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Algorithmic Issues and Applications of BOUT to Simulation of Realistic Tokamak Configurations

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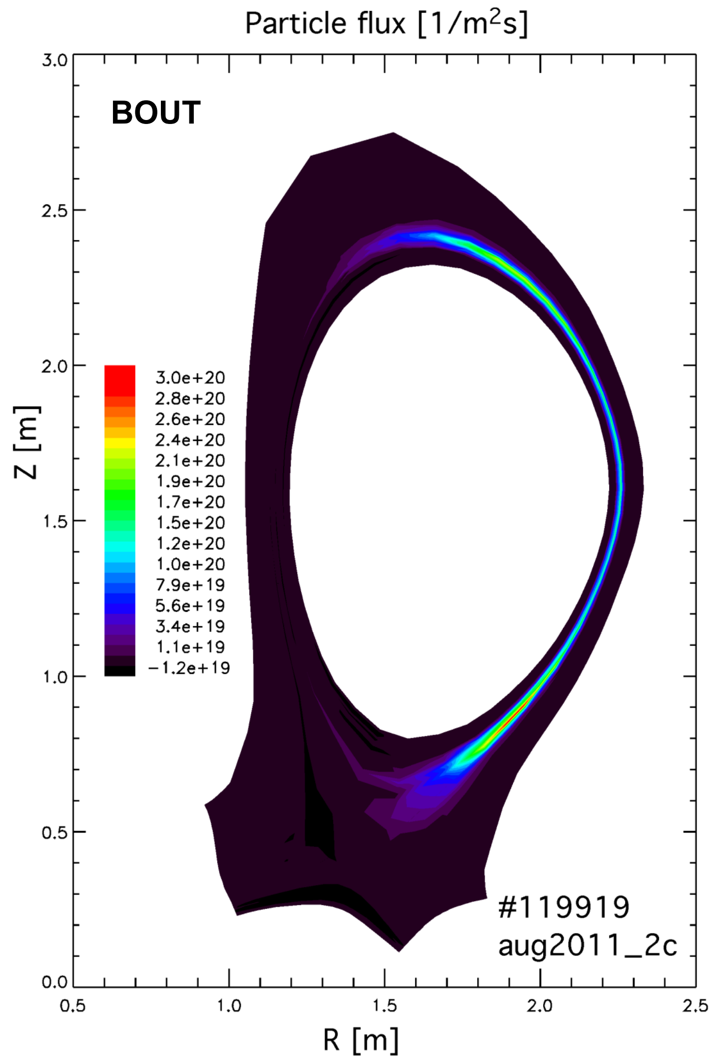
BOUT Simulations of Resistive Ballooning Turbulence in Edge Region for DIII-D Shot #119919

- Simulations of electrostatic resistive ballooning in DIII-D shot #119919, with full geometry and magnetic shear, crossing the separatrix
- Nonlinear BOUT equations for ion density, vorticity, electron and ion velocities, Ohm's law, and Maxwell's equations.
- In earlier work, we have suppressed a spatial odd-even mode ballooning along the field line by either filtering with $\nabla_{||}^2$ or $-\nabla_{||}^4$ diffusive operator added to right side of vorticity and ion density eqns, or with use of a staggered mesh for $\nabla_{||}$ representation. Parallel damping included here; no odd-even mode seen.
- **Simulation results with/without T_e fluctuations**
- **BOUT obtains steady-state turbulence with fluctuation amplitudes and transport that compare reasonably to the DIII-D data.**



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BOUT Simulation of Resistive Ballooning Turbulence for DIII-D Shot #119919 - Outline

- BOUT algorithmic issues -- control of an odd-even numerical contamination
- Electromagnetic simulations of resistive ballooning turbulence in single-null DIII-D geometry:
  - Case #1: No T_e fluctuations
  - Case #2: With T_e fluctuations
  - Case #3: With T_e fluctuations and electron parallel thermal conduction
  - Case #4: With T_e fluctuations, electron parallel thermal conduction, and $\nabla_{\parallel} = \mathbf{b}_0 \cdot \nabla + \tilde{\mathbf{b}} \cdot \nabla$ in the vorticity eqn.
- Comparison to probe data for DIII-D shot #119919. Shot #119919 is a well-characterized L-mode shot exhibiting steady-state turbulence.

BOUT06 produces expected ballooning-like turbulence in full DIII-D X-point geometry

- BOUT solves Braginskii-like fluid equations for fluid turbulence in various geometries

$$\frac{\partial N_i}{\partial t} + (V_E + V_\parallel) \bullet \nabla N_i = \left(\frac{2c}{eB}\right) b_0 \times \kappa \bullet (\nabla P_e - N_i e \nabla \phi) + \nabla_\parallel (j_\parallel / e) - N_i \nabla_\parallel V_{\parallel i}$$

$$\frac{\partial \varpi}{\partial t} + V_E \bullet \nabla \varpi = 2\omega_{ci} b_0 \times \kappa \bullet \nabla P + N_i Z_i e \frac{4\pi V_A^2}{c^2} \nabla_\parallel j_\parallel \quad \text{vorticity}$$

$$\frac{\partial V_{\parallel e}}{\partial t} = -\frac{e}{m_e} E_\parallel - \frac{1}{N m_e} (T_e \nabla_\parallel N_i) + 0.51 \nu_{ei} j_\parallel$$

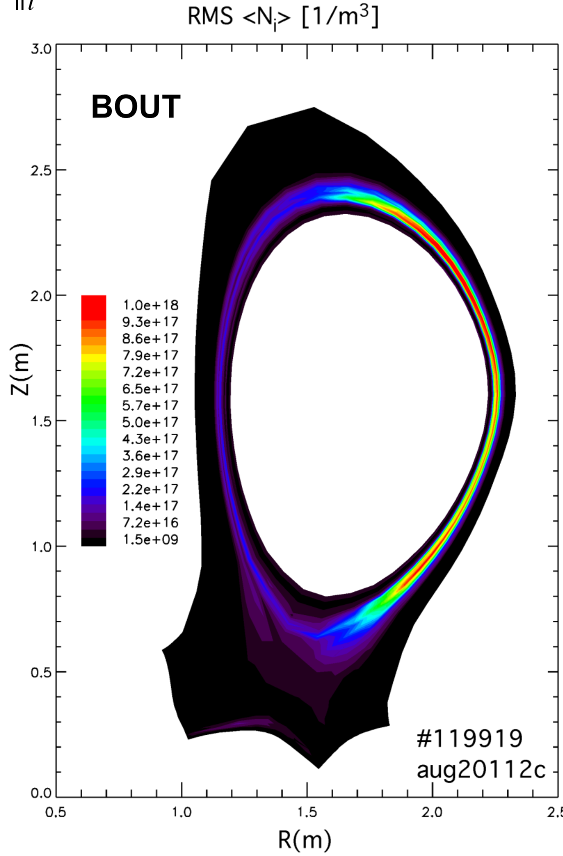
$$\frac{\partial V_{\parallel i}}{\partial t} + V_E \bullet \nabla V_{\parallel i} = -\frac{1}{N_i M_i} \nabla_\parallel P$$

$$\mathbf{E} = -\tfrac{1}{c}\tfrac{\partial}{\partial t}\mathbf{A}_\parallel - \nabla\phi, \quad -\nabla_\perp^2 \mathbf{A}_\parallel = \tfrac{4\pi}{c}\mathbf{j}_\parallel, \quad \mathbf{B} = \nabla \times \mathbf{A}_\parallel + \mathbf{B}_0$$

$$\varpi = \nabla \cdot (e Z_i N_i \nabla \phi) \approx e Z_i N_i \nabla^2 \phi \qquad \nabla_\parallel \approx \mathbf{b}_0 \cdot \nabla$$

- Electromagnetic with $\nabla_\parallel \approx \mathbf{b}_0 \cdot \nabla$
- Finite-difference equations
- Implicit time integration with PVODE
- Quasi-ballooning with zero-gradient radial bdry conditions

Distribution of <δN$_i$> in saturated turbulence



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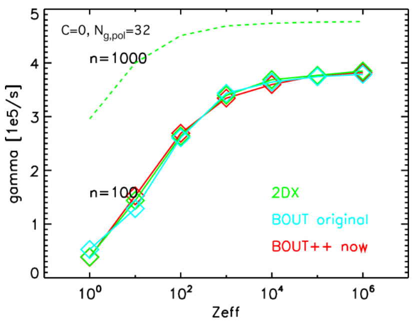
Resistive Ballooning Simulations with BOUT -- Odd-even Numerical Mode Can Be Controlled with Normalized Diffusive Damping in Poloidal Angle

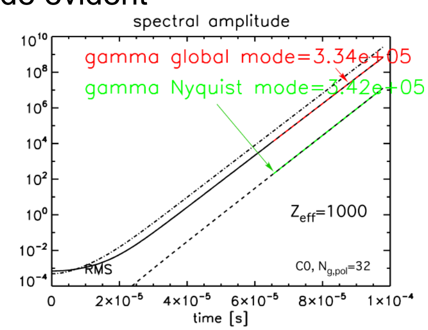
- Control the odd-even mode with $\partial/\partial t \rightarrow \partial/\partial t + \nu^*(k_\vartheta)$ in the vorticity and ion density eqns with diffusion operator in poloidal angle and normalized coeff.:

$$\nu^*(k_\theta) = \frac{C}{\Delta t}\left\{-(\Delta\theta/2)^2 D_\theta^2, (\Delta\theta/2)^4 D_\theta^4\right\} \rightarrow \frac{C}{\Delta t}\left\{\sin\left(k_\theta \Delta\theta/2\right)^2, \sin\left(k_\theta \Delta\theta/2\right)^4\right\}$$

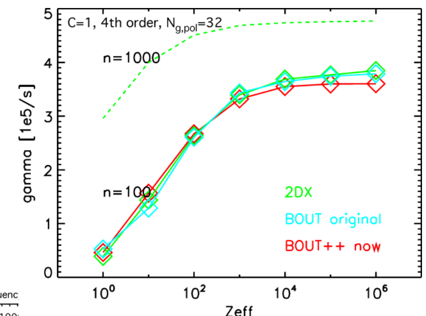
- Damping of the odd-even mode is proportional to normalized coefficient *C*

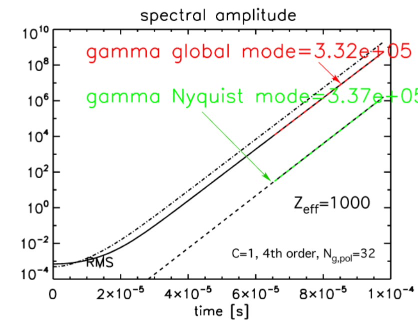
C=0
$n_{g,pol}$=32 4th order
Odd-even mode evident

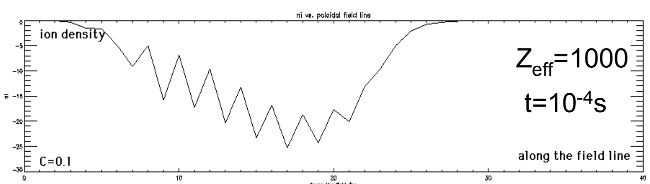


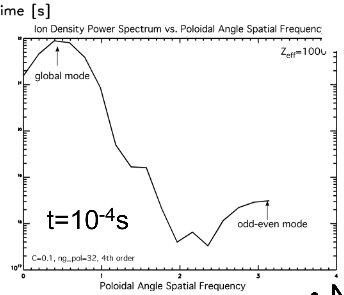


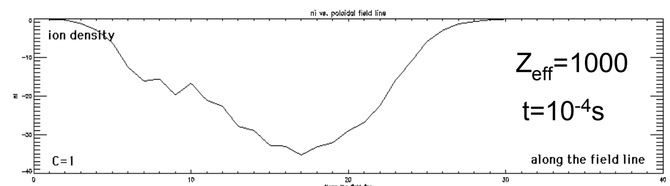
C=1
$n_{g,pol}$=32 4th order
Damping of odd-even mode











A(Nyquist)/A(global)~$(\Delta x_{||}^3)\,(\Delta x_{||}/2L_{||})^n$, n= 2,4

- Note: Staggered grid for $\nabla_{||}$ representation resolves problem with $\nabla_{||}^2$ finite-difference stencil & also removes odd-even mode

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Case #1: BOUT06 produces expected ballooning-like turbulence in full DIII-D X-point geometry

- Consider the following simplified equation set in the BOUT06 framework:

$$\frac{\partial N_i}{\partial t} + (V_E + V_\parallel) \bullet \nabla N_i = \left(\frac{2c}{eB}\right) b_0 \times \kappa \bullet (\nabla P_e - N_i e \nabla \phi) + \nabla_\parallel (j_\parallel / e) - N_i \nabla_\parallel V_{\parallel i}$$

$$\frac{\partial \varpi}{\partial t} + V_E \bullet \nabla \varpi = 2\omega_{ci} b_0 \times \kappa \bullet \nabla P \quad + \quad N_i Z_i e \frac{4\pi V_A^2}{c^2} \nabla_\parallel j_\parallel$$

$$\frac{\partial V_{\parallel e}}{\partial t} = -\frac{e}{m_e} E_\parallel - \frac{1}{N m_e} (T_e \nabla_\parallel N_i) + 0.51 \nu_{ei} j_\parallel$$

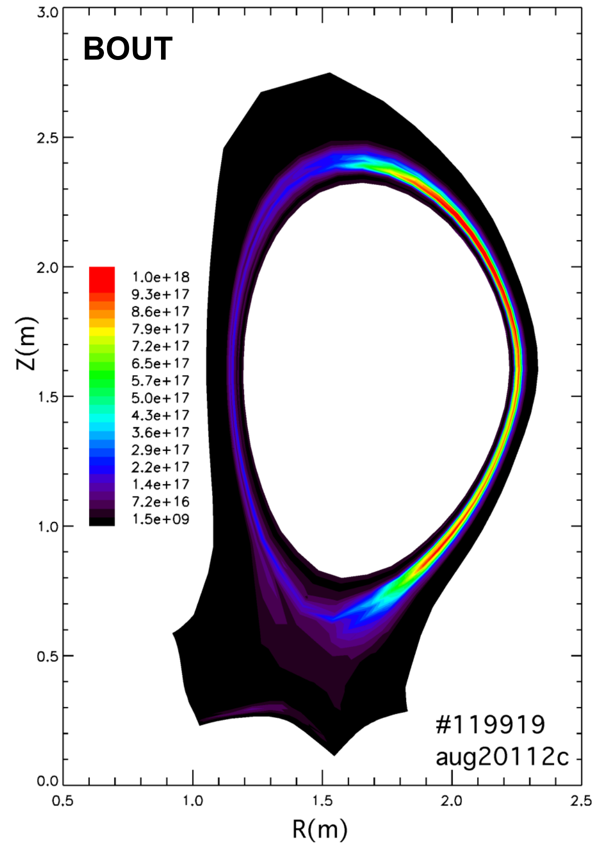
$$\frac{\partial V_{\parallel i}}{\partial t} + V_E \bullet \nabla V_{\parallel i} = -\frac{1}{N_i M_i} \nabla_\parallel P$$

$$\mathbf{E} = -\frac{1}{c}\frac{\partial}{\partial t}\mathbf{A}_\parallel - \nabla\phi, \quad -\nabla_\perp^2 \mathbf{A}_\parallel = \frac{4\pi}{c}\mathbf{j}_\parallel, \quad \mathbf{B} = \nabla \times \mathbf{A}_\parallel + \mathbf{B}_0$$

$$\varpi = \nabla \cdot (e Z_i N_i \nabla \phi) \approx e Z_i N_i \nabla^2 \phi \quad \nabla_\parallel \approx \mathbf{b}_0 \cdot \nabla$$

- Electromagnetic with $\nabla_\parallel \approx \mathbf{b}_0 \cdot \nabla$
- Actual DIII-D geometry
- DIII-D - like fixed background profiles for shot 119919
- No T_e fluctuations

Distribution of <δN_i> in saturated turbulence



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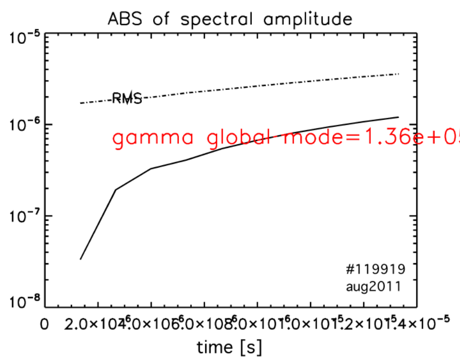
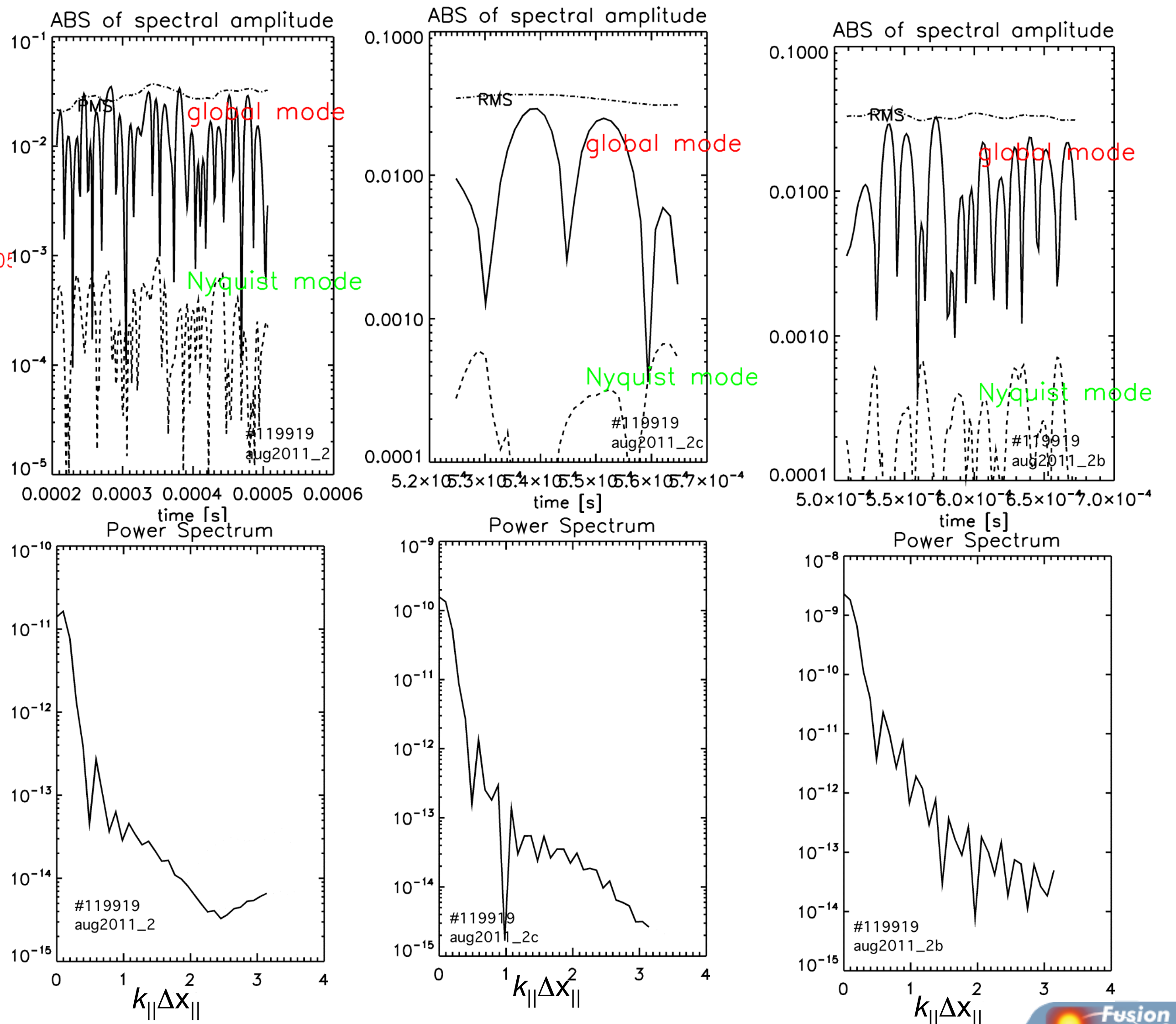
BOUT-06 produces saturated turbulence for DIII-D geometry with no T_e fluctuations

- Evolution of density fluctuations leading to saturated amplitudes and spectra

BOUT





- No T_e fluctuations

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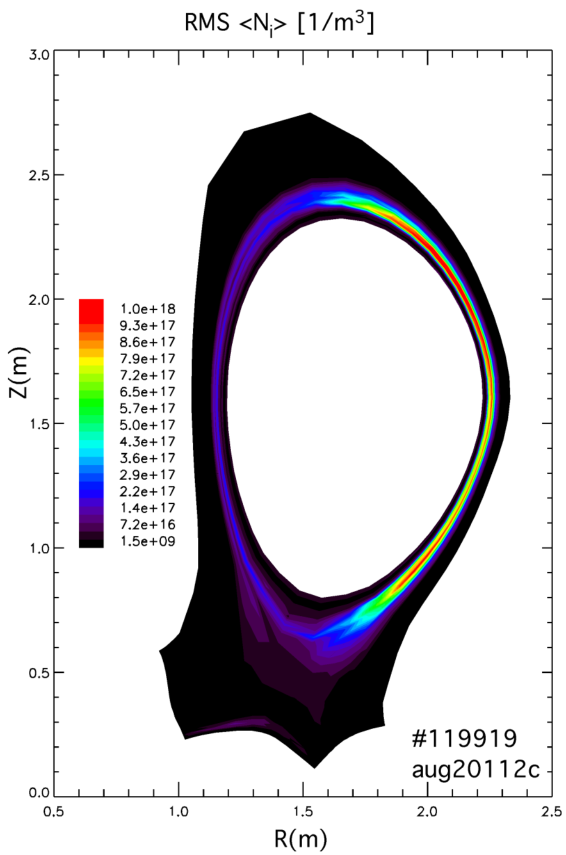
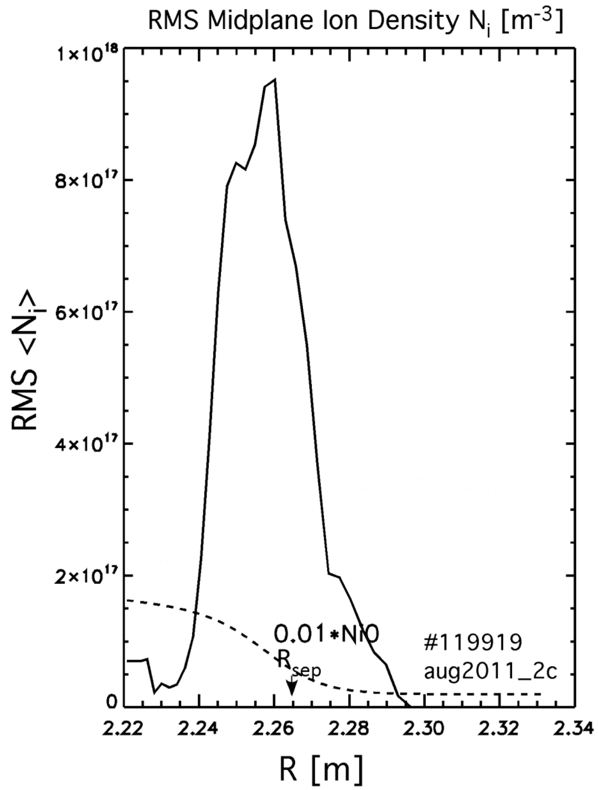
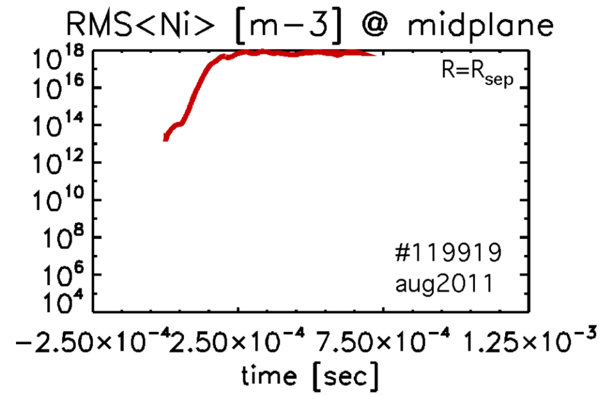
Time-averaged ion density fluctuations in the midplane saturate at ~10% and peak near R_{sep}

BOUT







- No T_e fluctuations

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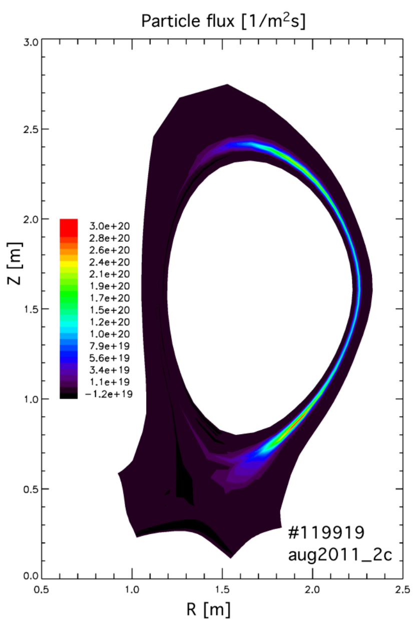
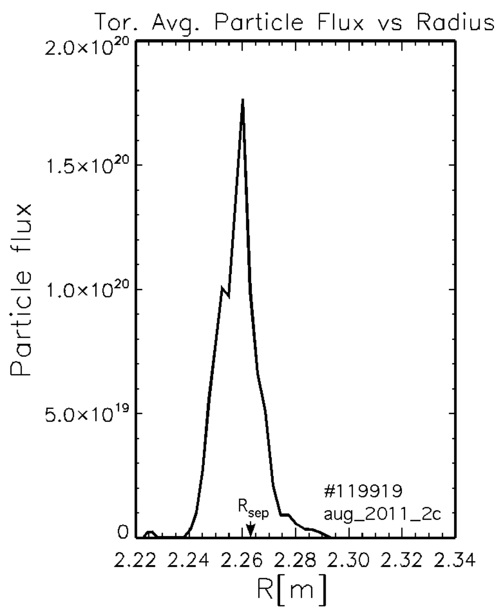
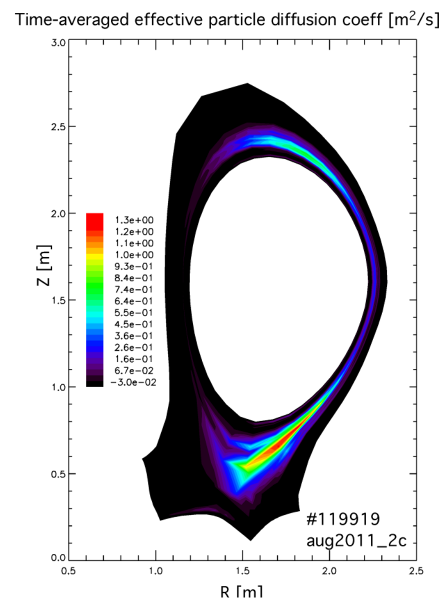
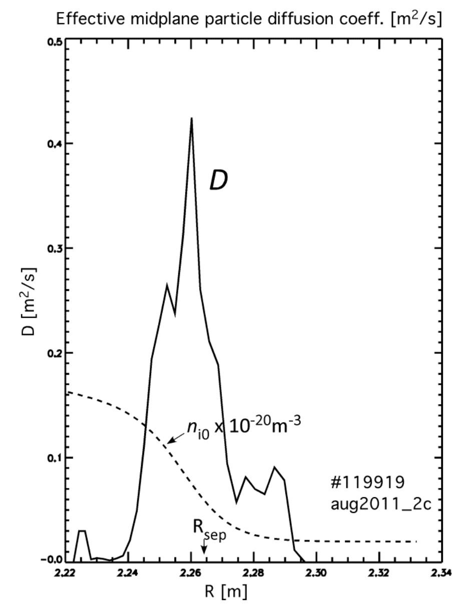
Time-averaged ion particle diffusion coefficient saturates at O(0.4) m^2/s in the midplane and peaks near R_{sep}

BOUT









- No T_e fluctuations

- In this model with no temperature fluctuations and if $\nabla \ln(T_{eq}) = \nabla \ln(n_{eq})$, then $\chi_{conv} \approx (3/2)D$

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Case #2: Include Advection of Temperature T_e in BOUT06 Equations for Resistive Ballooning

- Consider the following simplified equation set in the BOUT06 framework:

$$\frac{\partial N_i}{\partial t} + (V_E + V_\parallel) \bullet \nabla N_i = \left(\frac{2c}{eB}\right) b_0 \times \kappa \bullet (\nabla P_e - N_i e \nabla\phi) + \nabla_\parallel (j_\parallel / e) - N_i \nabla_\parallel V_{\parallel i}$$

$$\frac{\partial \varpi}{\partial t} + V_E \bullet \nabla \varpi = 2\omega_{ci} b_0 \times \kappa \bullet \nabla P \quad + \quad N_i Z_i e \frac{4\pi V_A^2}{c^2} \nabla_\parallel j_\parallel$$

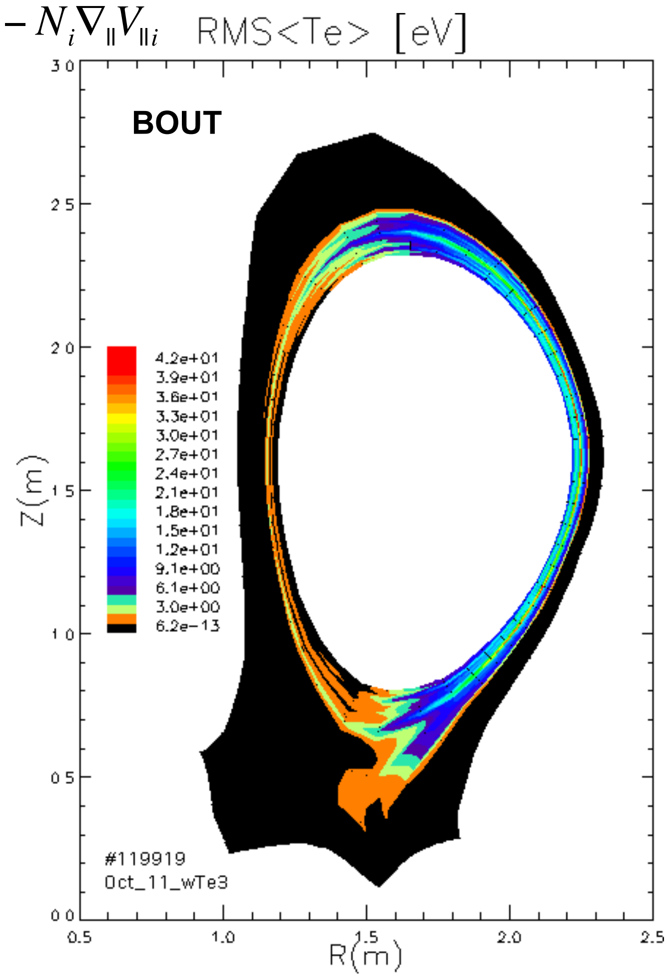
$$\frac{\partial V_{\parallel e}}{\partial t} = -\frac{e}{m_e} E_\parallel - \frac{1}{N m_e} (T_e \nabla_\parallel N_i) + 0.51 \nu_{ei} j_\parallel$$

$$\frac{\partial V_{\parallel i}}{\partial t} + V_E \bullet \nabla V_{\parallel i} = -\frac{1}{N_i M_i} \nabla_\parallel P$$

$$\frac{\partial T_e}{\partial t} + V_E \bullet \nabla T_{e0} = 0$$

$$\mathbf{E} = -\frac{1}{c}\frac{\partial}{\partial t}\mathbf{A}_\parallel - \nabla\phi, \quad -\nabla_\perp^2 \mathbf{A}_\parallel = \frac{4\pi}{c}\mathbf{j}_\parallel, \quad \mathbf{B} = \nabla \times \mathbf{A}_\parallel + \mathbf{B}_0$$

$$\varpi = \nabla \cdot (e Z_i N_i \nabla\phi) \approx e Z_i N_i \nabla^2 \phi \quad \nabla_\parallel \approx \mathbf{b}_0 \cdot \nabla$$



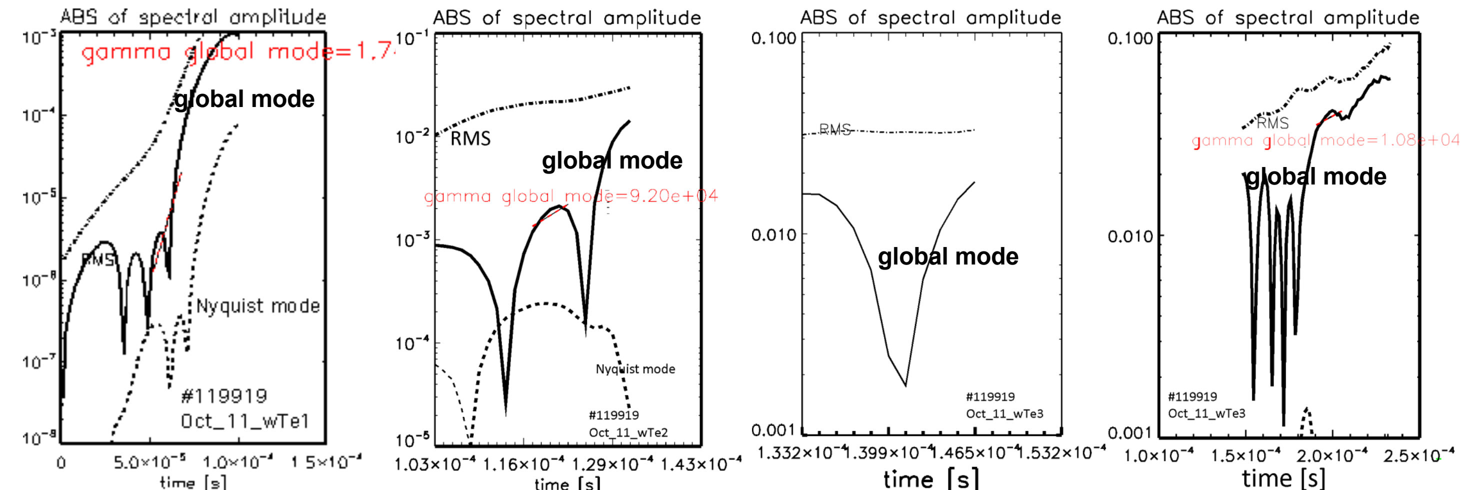
- Electromagnetic with $\nabla_\parallel \approx \mathbf{b}_0 \cdot \nabla$
- Actual DIII-D geometry
- DIII-D - like fixed background profiles for shot 119919
- Includes T_e fluctuations

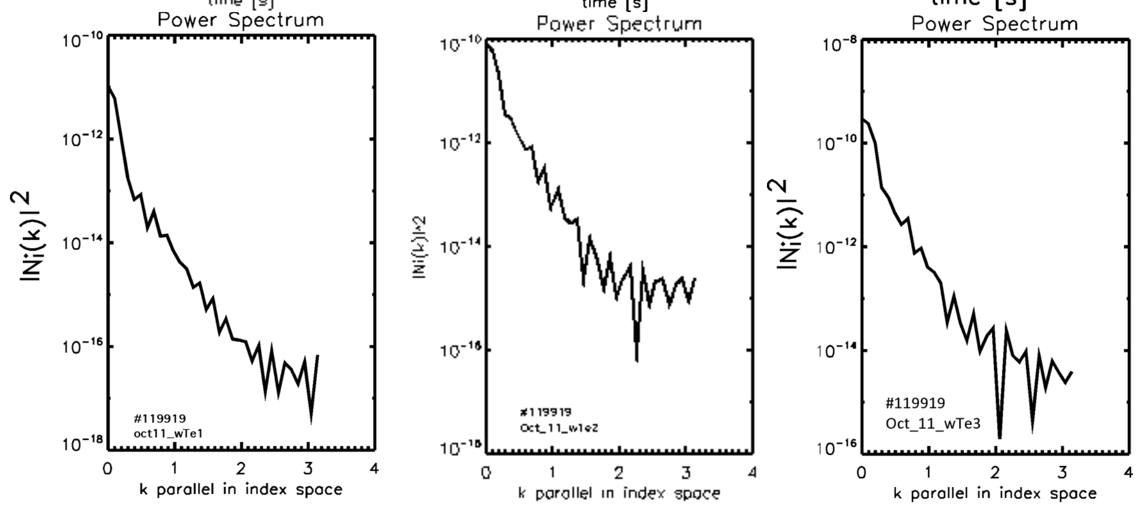
B. Cohen, et al., APS DPP 2011

BOUT-06 produces saturated turbulence for DIII-D geometry with T_e fluctuations

- Evolution of density fluctuations leading to saturated amplitudes and spectra

BOUT





- Saturation at ~1.5×10^{-4}s followed by unphysical growth

- With T_e fluctuations

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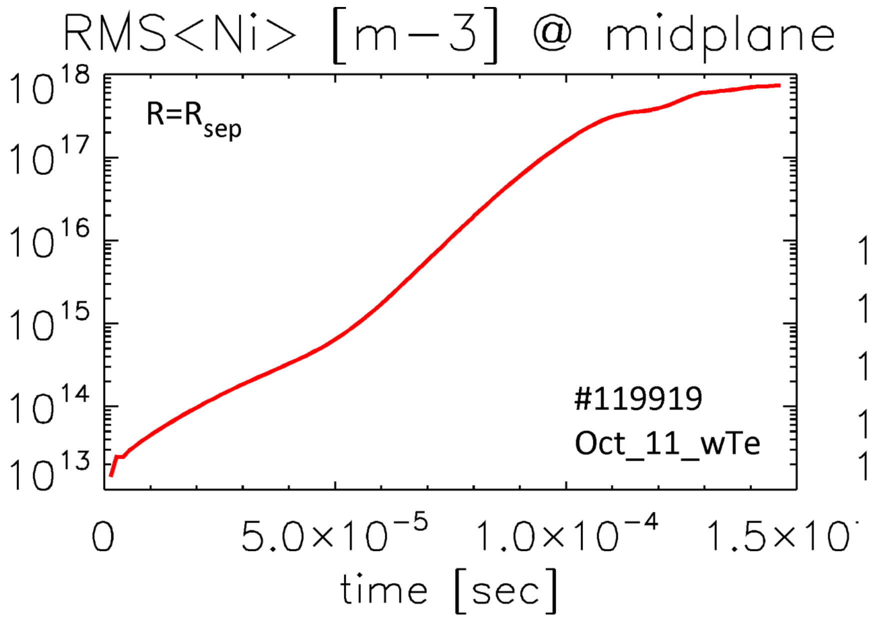
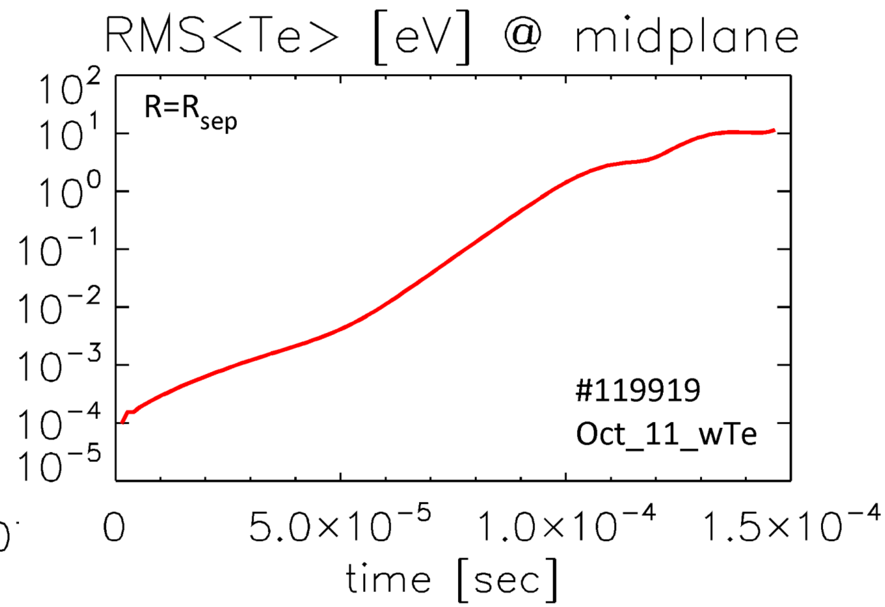
Ion density and electron T_e fluctuations in the midplane saturate at ~1.5×10^{-4} sec

BOUT





- With T_e fluctuations

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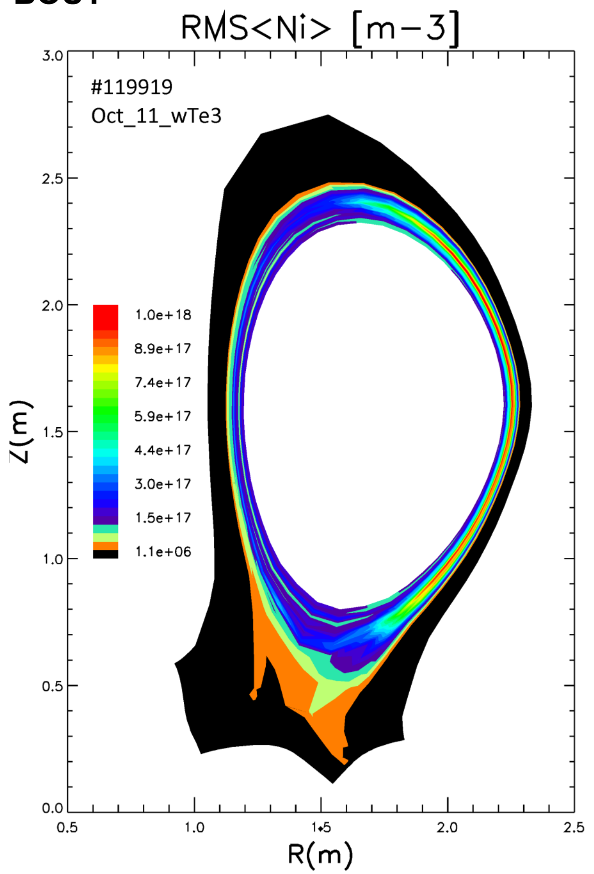
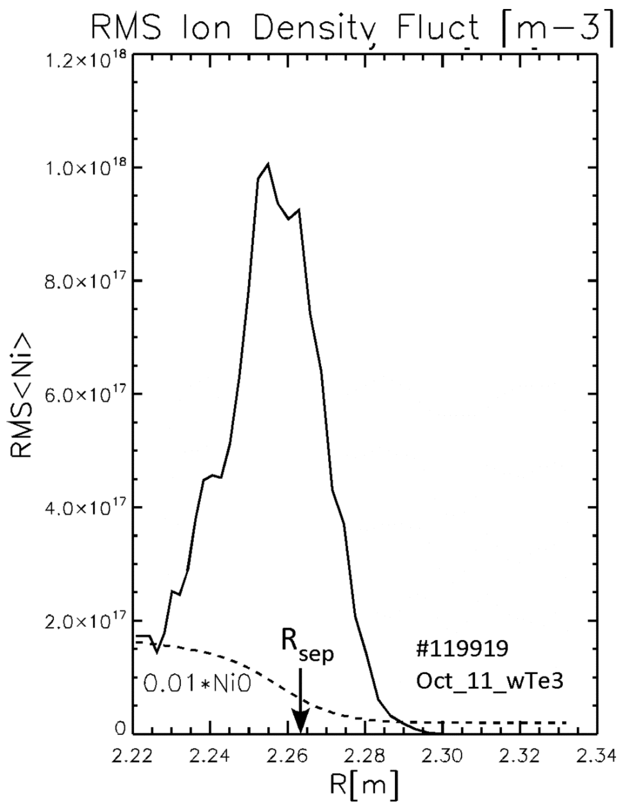
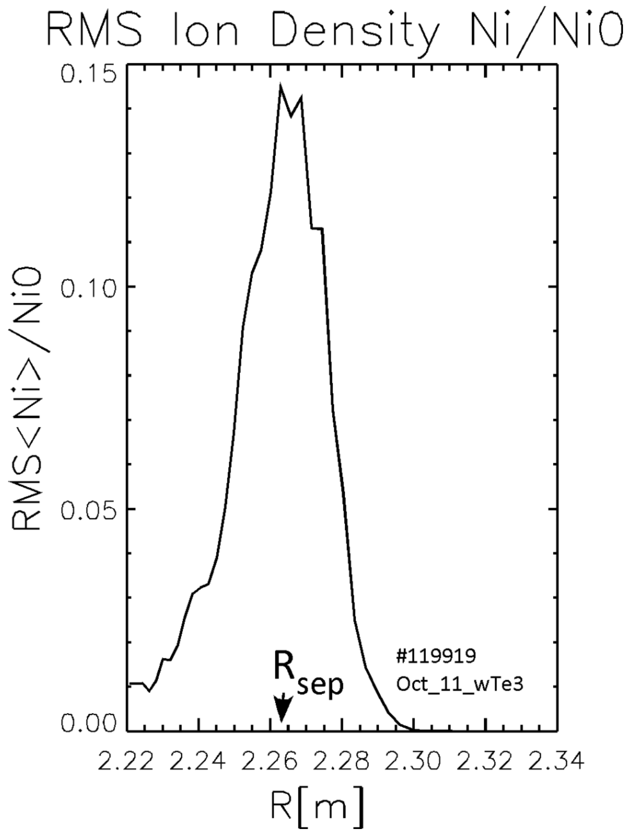
Time-averaged ion density fluctuations in the midplane saturate at ~15% relative amplitude and peak near R_{sep}

BOUT







- With T_e fluctuations

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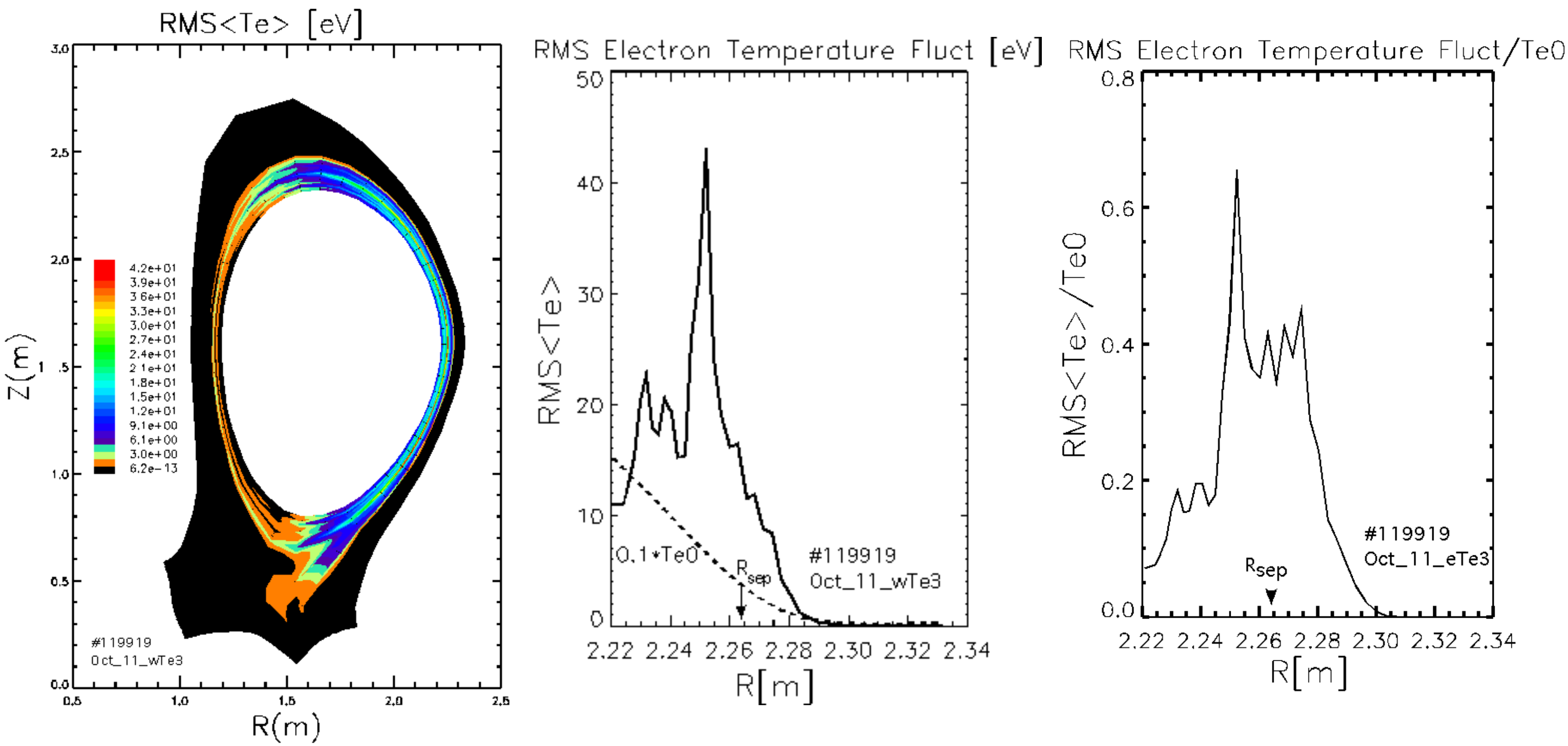
Time-averaged T_e fluctuations in the midplane saturate at ~40-60% relative amplitude and peak near R_{sep}

BOUT



- With T_e fluctuations

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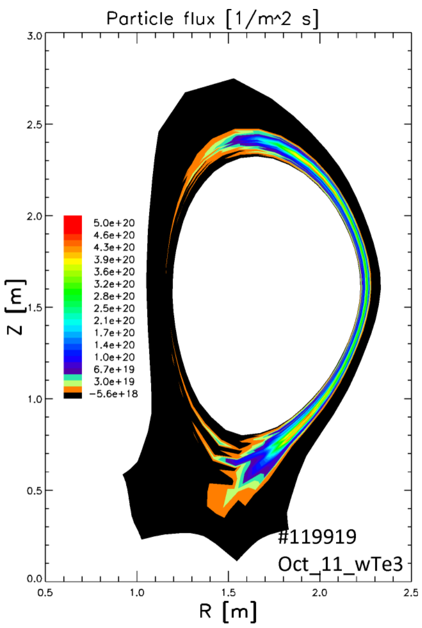
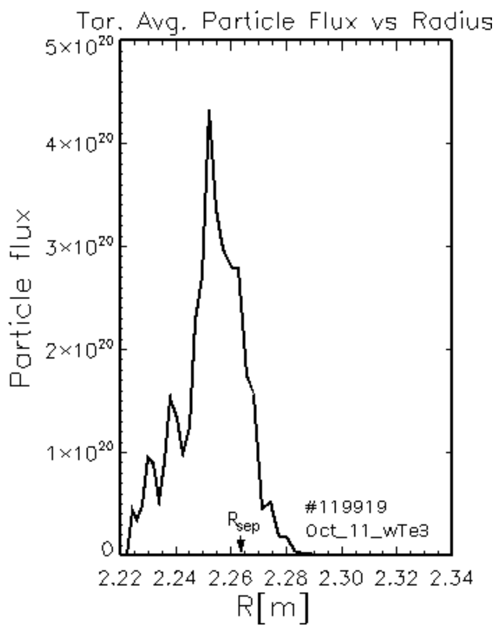
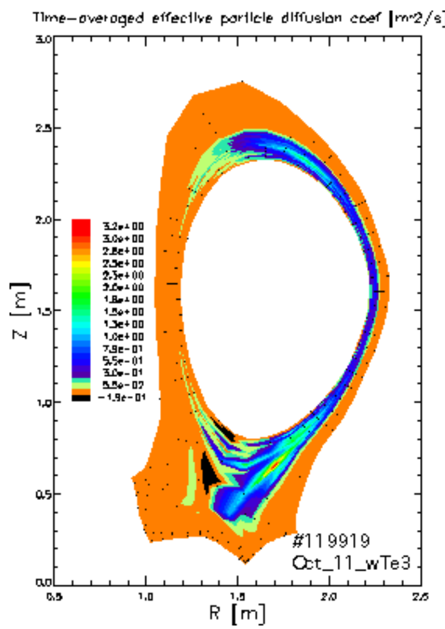
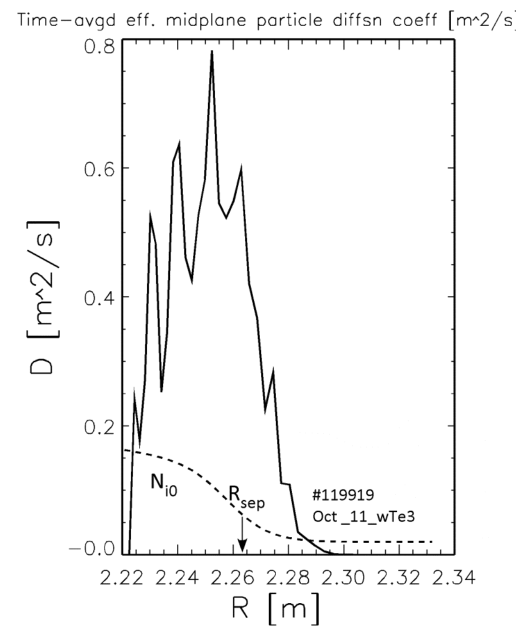
Time-averaged ion particle diffusion coefficient in the midplane saturates at O(1) m²/s and peaks near R_{sep}

BOUT









- With T_e fluctuations

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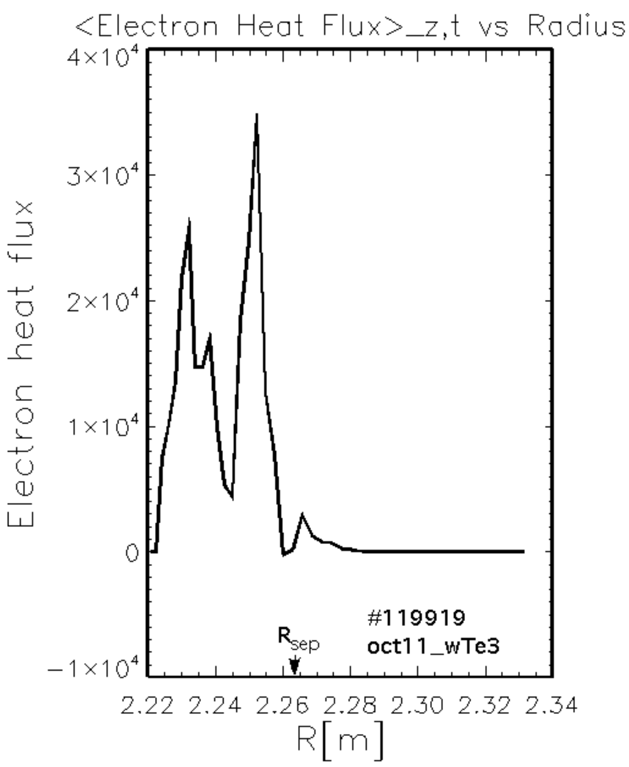
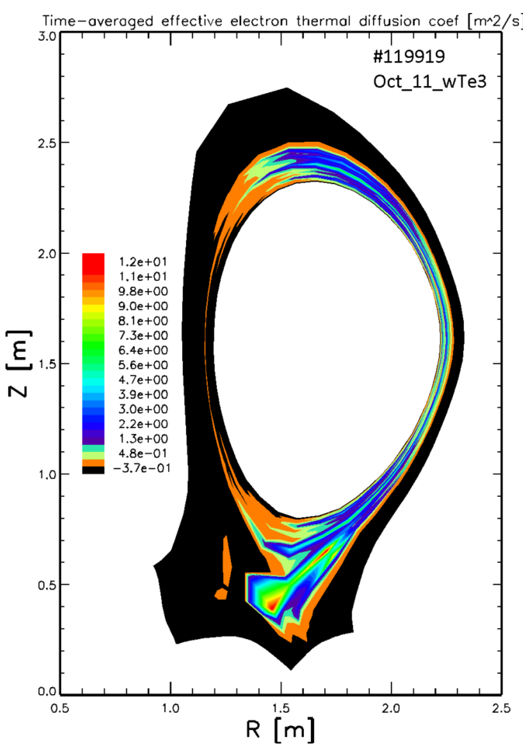
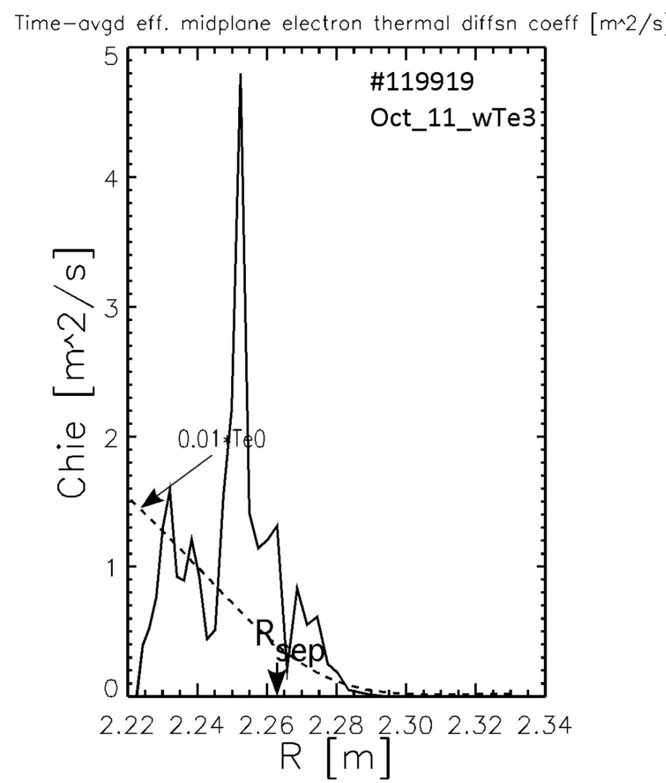
Time-averaged electron thermal diffusion coefficient in the midplane saturates at 1-5 m^2/s and peaks near R_{sep}

- Bout with T_e fluctuations







$$\text{Note: Here heat flux (conductive)} = N_0 < \delta\tilde{v}_r \delta T_e >_{tor,t}, \text{ and } \chi_e = -N_0 < \delta\tilde{v}_r \delta T_e >_{tor,t} / N_0 \nabla T_{e0}$$

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Case #3: Include Advection of T_e in BOUT06 Equations for Resistive Ballooning with Parallel Electron Thermal Conduction

- Consider the following simplified equation set in the BOUT06 framework:

$$\frac{\partial N_i}{\partial t} + (V_E + V_\parallel) \bullet \nabla N_i = \left(\frac{2c}{eB}\right) b_0 \times \kappa \bullet (\nabla P_e - N_i e \nabla \varphi) + \nabla_\parallel (j_\parallel / e) - N_i \nabla_\parallel V_{\parallel i}$$

$$\frac{\partial \varpi}{\partial t} + V_E \bullet \nabla \varpi = 2\omega_{ci} b_0 \times \kappa \bullet \nabla P \quad + \quad N_i Z_i e \frac{4\pi V_A^2}{c^2} \nabla_\parallel j_\parallel$$

$$\frac{\partial V_{\parallel e}}{\partial t} = -\frac{e}{m_e} E_\parallel - \frac{1}{N m_e} (T_e \nabla_\parallel N_i) + 0.51 \nu_{ei} j_\parallel$$

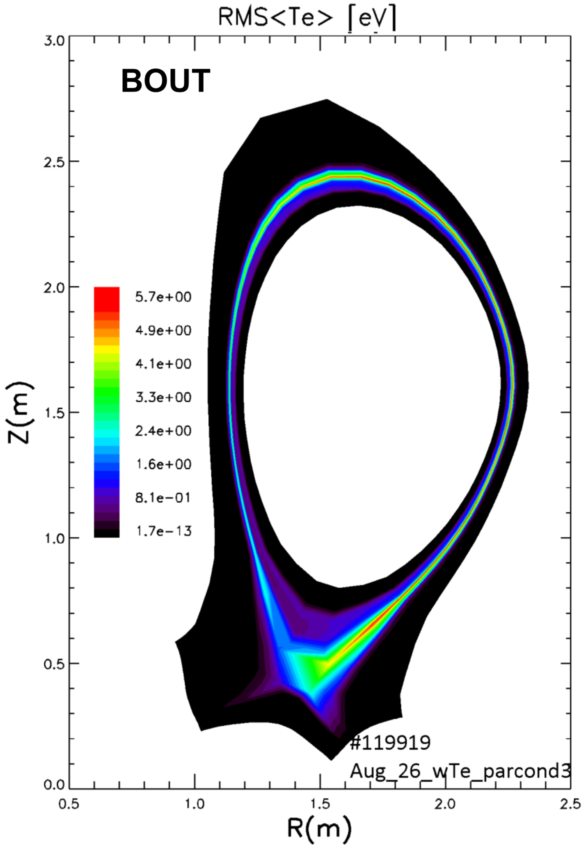
$$\frac{\partial V_{\parallel i}}{\partial t} + V_E \bullet \nabla V_{\parallel i} = -\frac{1}{N_i M_i} \nabla_\parallel P$$

$$\frac{\partial T_e}{\partial t} + V_E \bullet \nabla T_{e0} = \frac{2}{3N_0} \nabla \bullet \left(\kappa_\parallel^e \nabla_\parallel T_e\right), \quad \kappa_\parallel^e = 3.2 \frac{N_0 T_{e0} \tau_e}{m_e}$$

$$\mathbf{E} = -\frac{\mathbf{1}}{c} \frac{\partial}{\partial t} \mathbf{A}_\parallel - \nabla \varphi, \quad -\nabla_\perp^2 \mathbf{A}_\parallel = \frac{4\pi}{c} \mathbf{j}_\parallel, \quad \mathbf{B} = \nabla \times \mathbf{A}_\parallel + \mathbf{B}_0$$

$$\varpi = \nabla \cdot (e Z_i N_i \nabla \varphi) \approx e Z_i N_i \nabla^2 \varphi \qquad \nabla_\parallel = \mathbf{b}_0 \cdot \nabla$$

- Electromagnetic with $\nabla_\parallel = \mathbf{b}_0 \cdot \nabla$
- Actual DIII-D geometry
- DIII-D - like fixed background profiles for shot #119919
- Includes T_e fluctuations & parallel heat conduction



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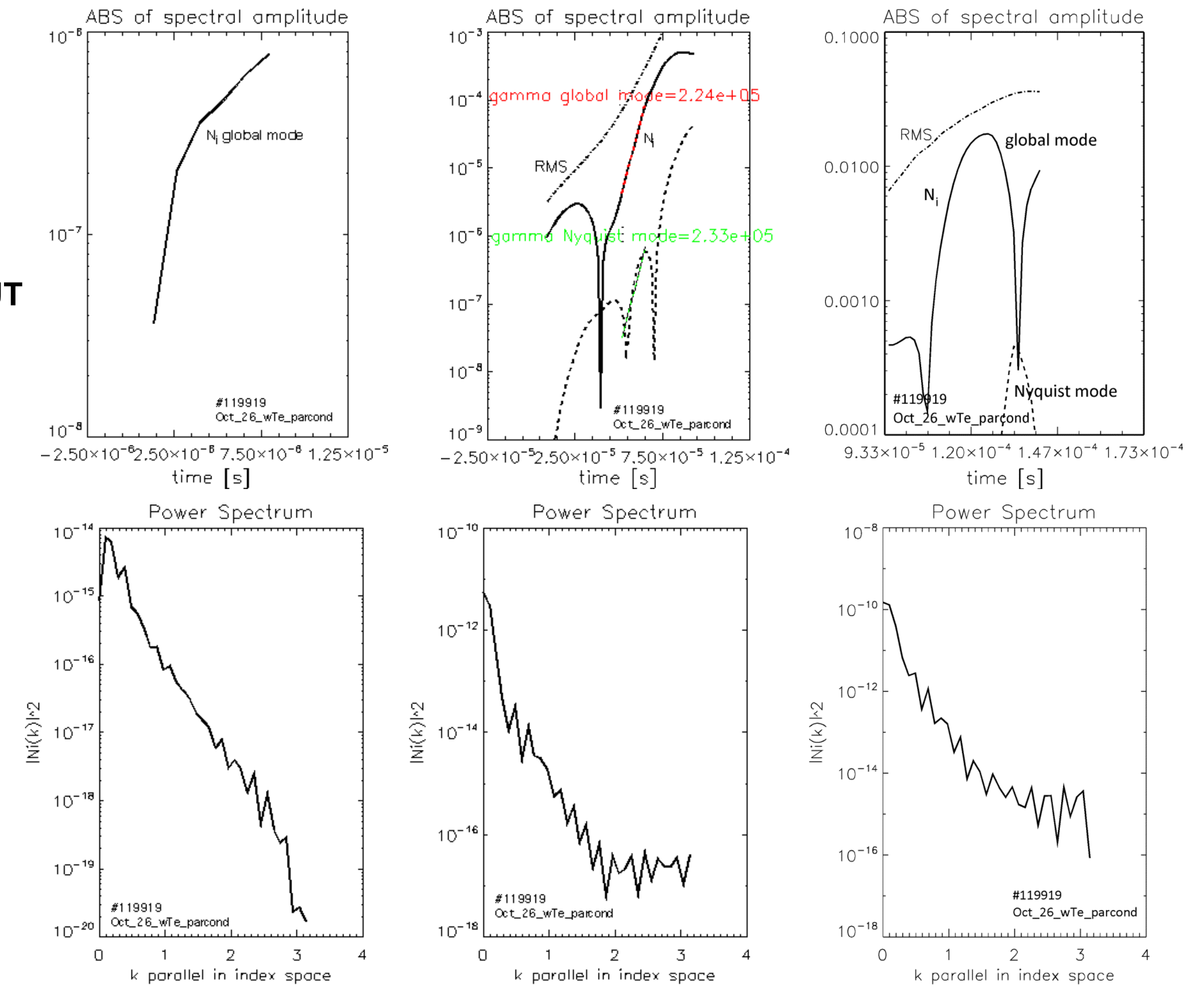
BOUT-06 produces saturated turbulence for DIII-D geometry with T_e fluctuations and electron parallel thermal conduction

- Evolution of density fluctuations leading to saturated amplitudes and spectra

BOUT



- Saturation at $\sim 1.5 \times 10^{-4}$s

- With T_e fluctuations and electron parallel thermal conduction

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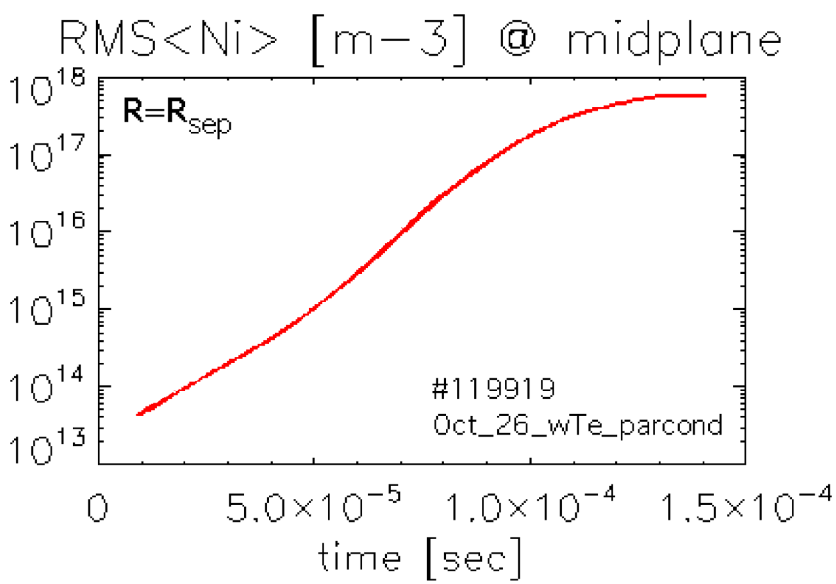
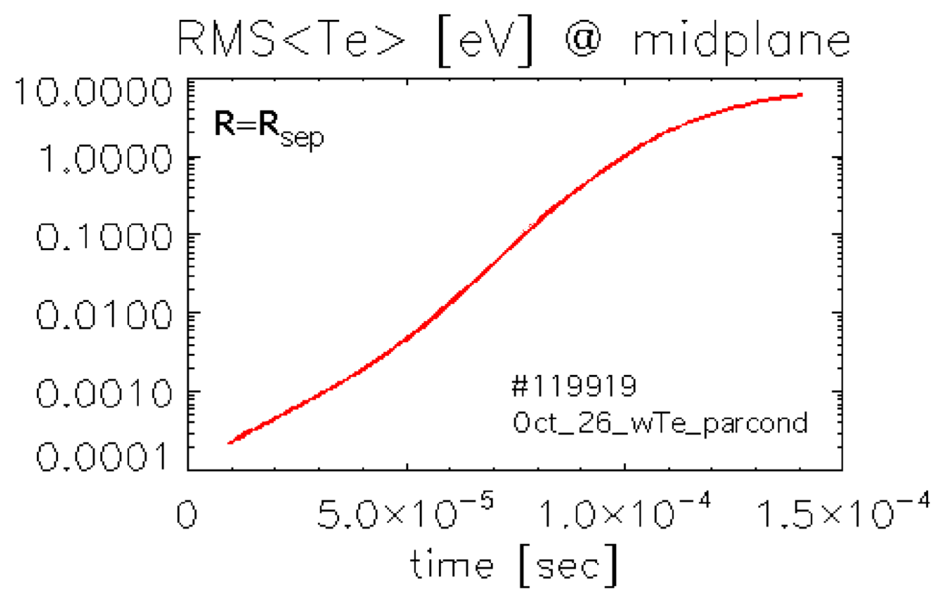
History of rms fluctuation amplitudes in midplane at separatrix with electron parallel thermal conduction

BOUT





- With T_e fluctuations and electron parallel thermal conduction

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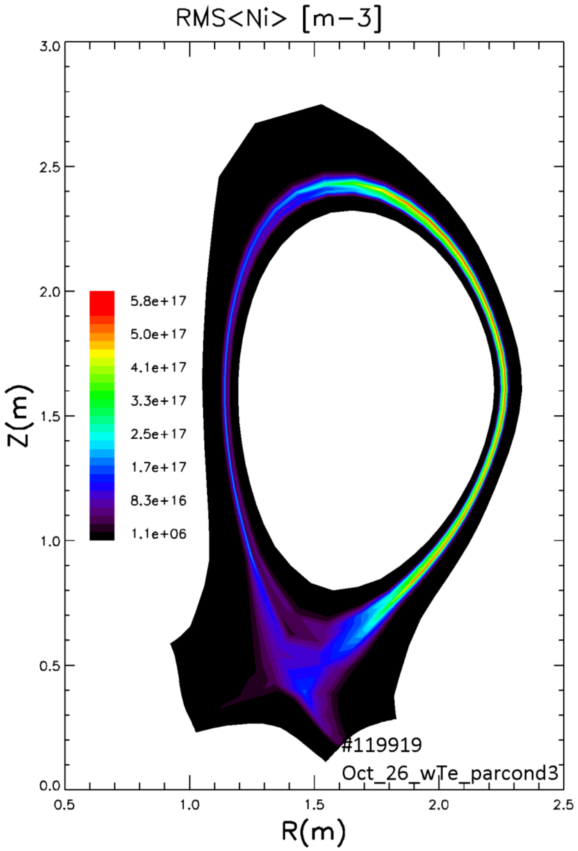
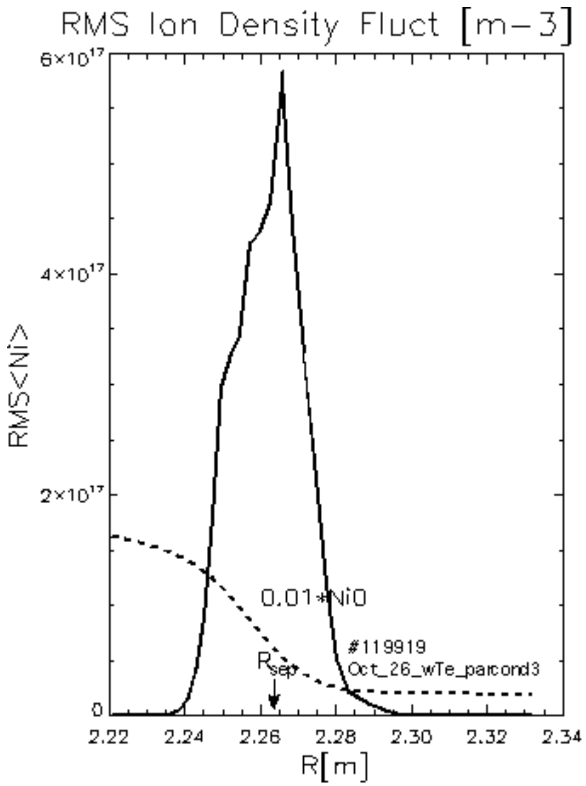
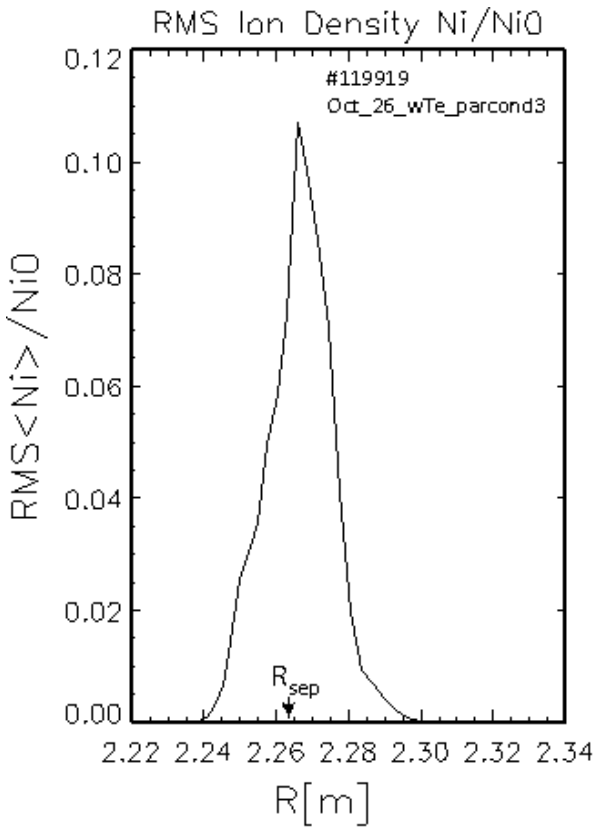
Time-averaged ion density fluctuations in the midplane saturate at ~11% and peak near R_{sep}

BOUT





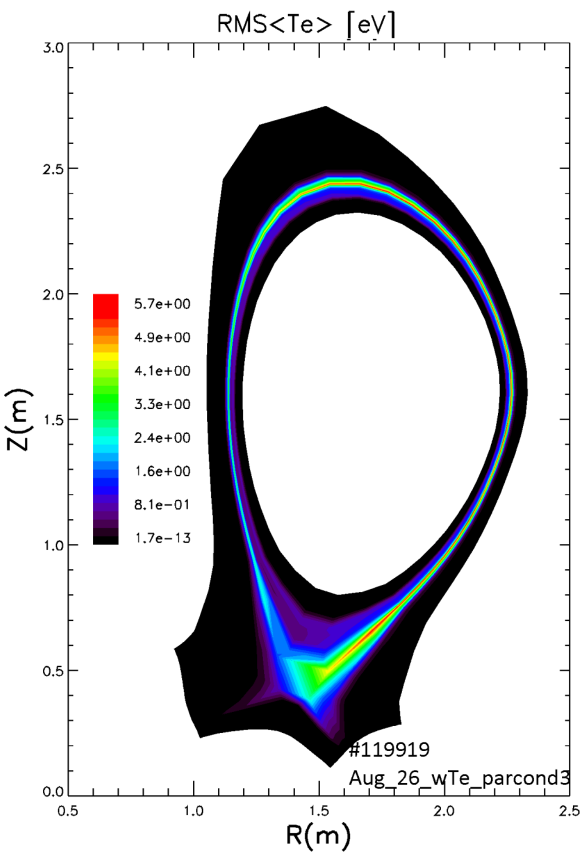


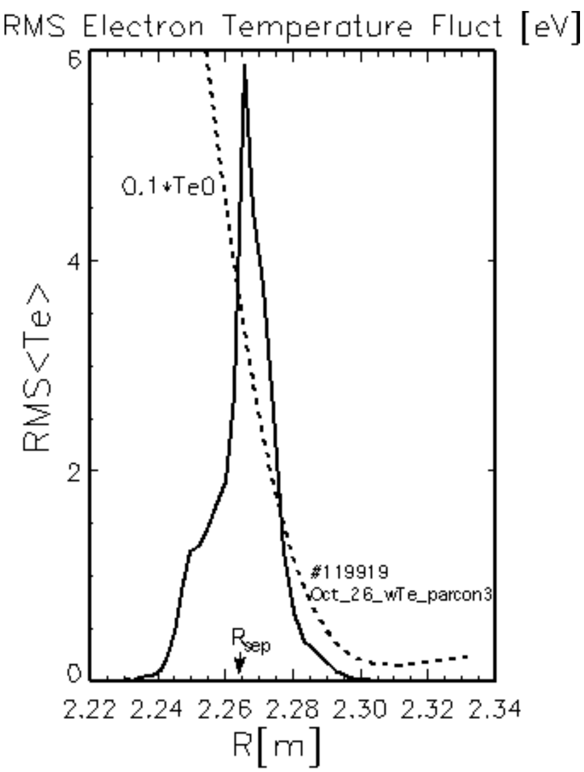
- With T_e fluctuations and electron parallel thermal conduction

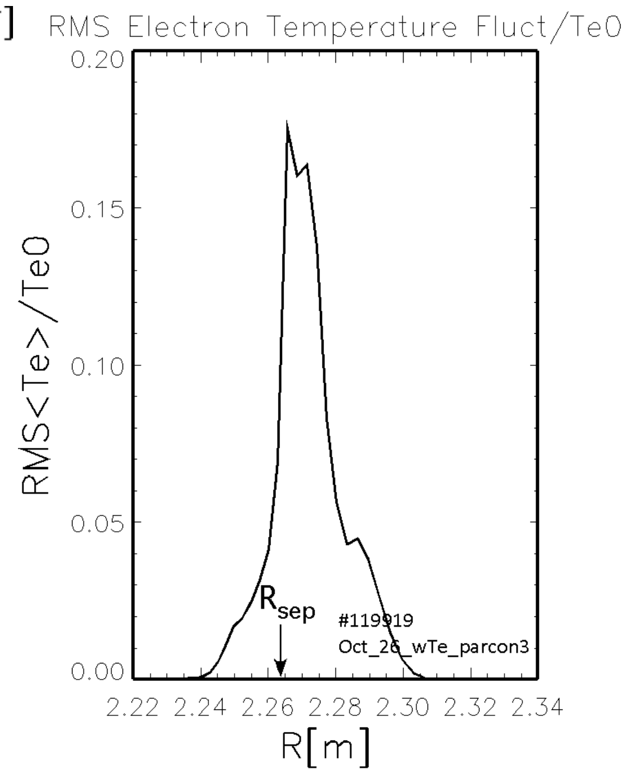
B. Cohen, et al., APS DPP 2011

Time-averaged T_e fluctuations in the midplane peak near the R_{sep} and saturate at ~18% relative amplitude

BOUT





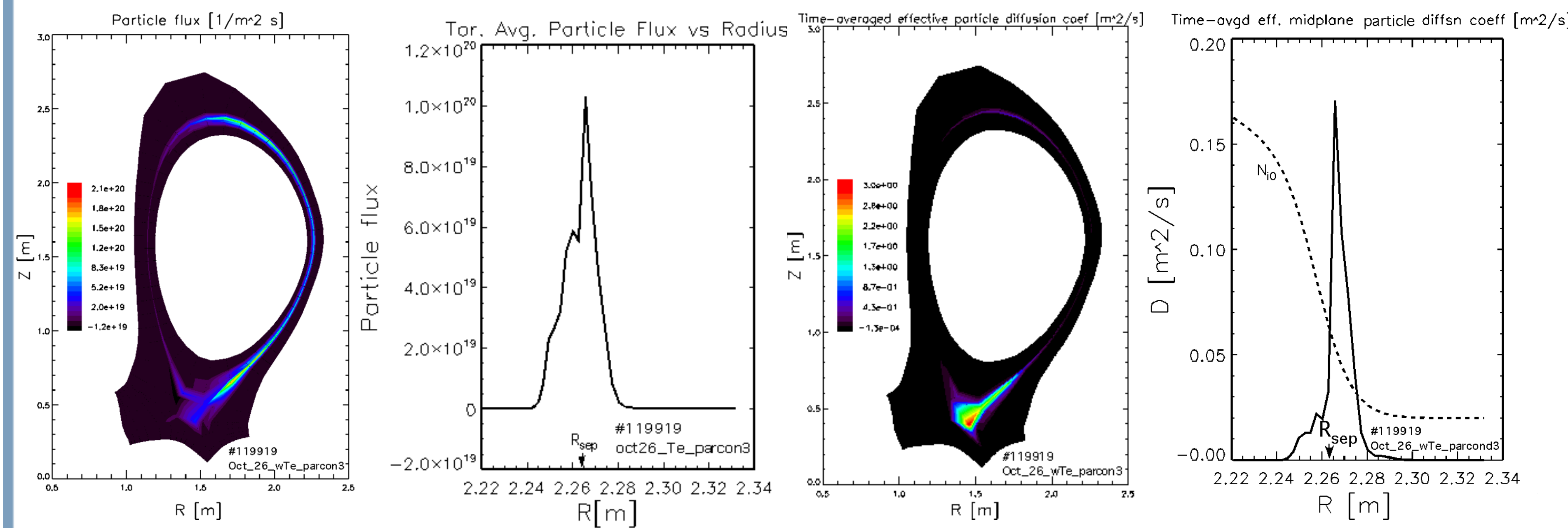


- With T_e fluctuations and electron parallel thermal conduction

B. Cohen, et al., APS DPP 2011

Time-averaged ion particle diffusion coefficient in the midplane saturates at < 0.2 m^2/s and peaks near R_{sep}

BOUT

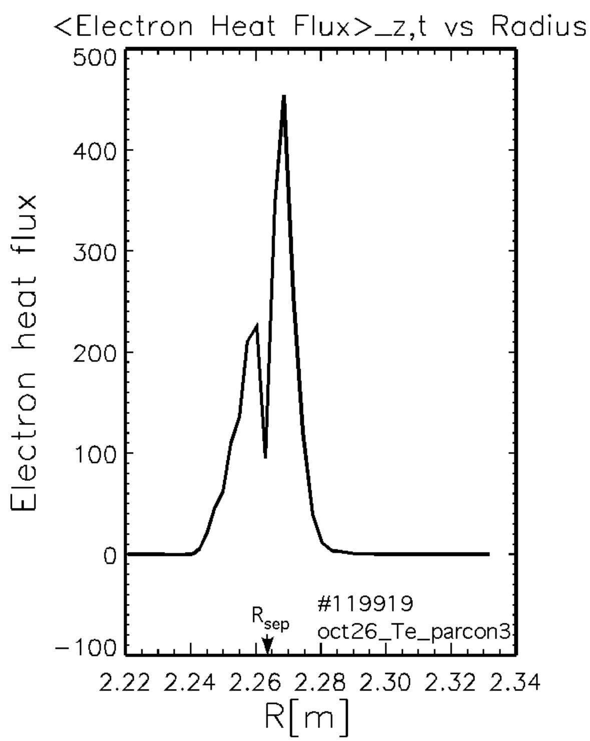


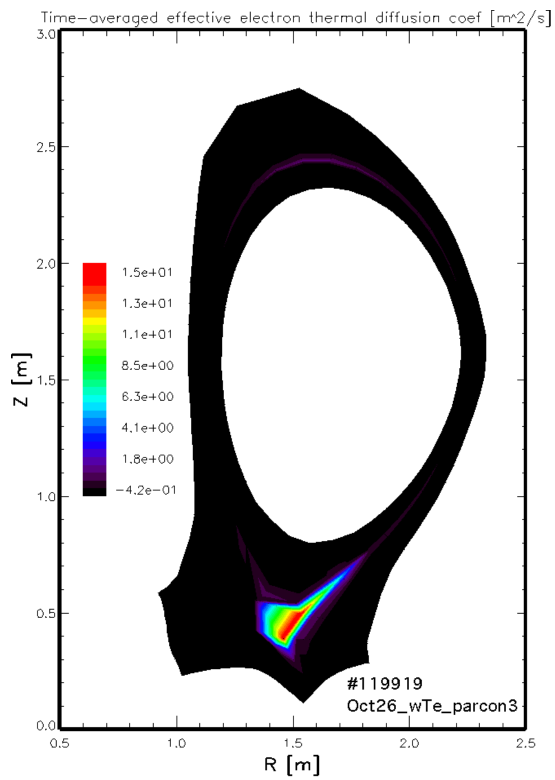
- With T_e fluctuations and electron parallel thermal conduction

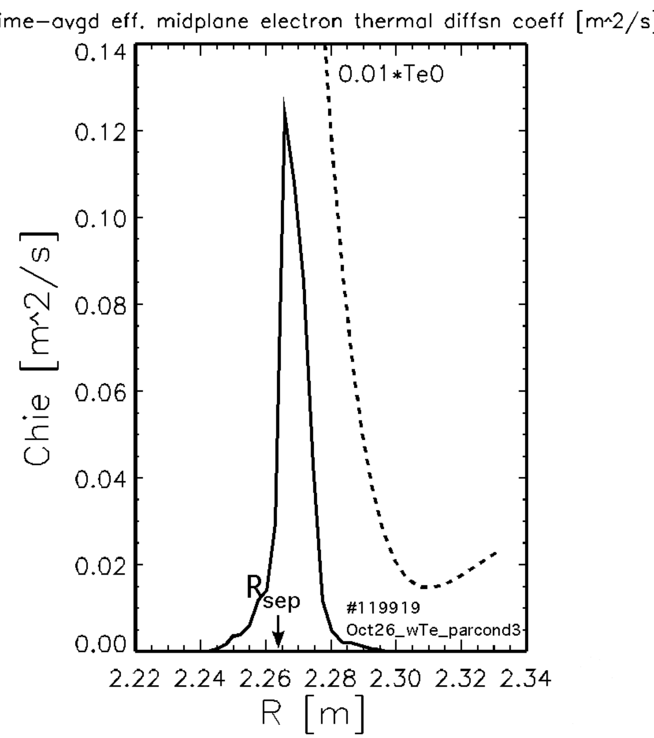
B. Cohen, et al., APS DPP 2011

Time-averaged electron thermal diffusion coefficient in the midplane saturates at ~0.1 m^2/s and peaks near R_{sep}

BOUT







Note: Here heat flux (conductive) $= N_0 < \delta\tilde{v}_r \delta T_e >_{tor,t}$, and $\chi_e = -N_0 < \delta\tilde{v}_r \delta T_e >_{tor,t} / N_0 \nabla T_{e0}$

- With T_e fluctuations and electron parallel thermal conduction

B. Cohen, et al., APS DPP 2011

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Case #4: Include Advection of Temperature T_e in BOUT06 Equations for Resistive Ballooning with Magnetic Flutter

- Consider the following simplified equation set in the BOUT06 framework:

$$\frac{\partial N_i}{\partial t} + (V_E + V_\parallel) \bullet \nabla N_i = \left(\frac{2c}{eB}\right) b_0 \times \kappa \bullet (\nabla P_e - N_i e \nabla \varphi) + \nabla_\parallel (j_\parallel / e) - N_i \nabla_\parallel V_{\parallel i}$$

$$\frac{\partial \varpi}{\partial t} + V_E \bullet \nabla \varpi = 2\omega_{ci} b_0 \times \kappa \bullet \nabla P \quad + \quad N_i Z_i e \frac{4\pi V_A^2}{c^2} \nabla_\parallel j_\parallel$$

$$\frac{\partial V_{\parallel e}}{\partial t} = -\frac{e}{m_e} E_\parallel - \frac{1}{N m_e}(T_e \nabla_\parallel N_i) + 0.51 \nu_{ei} j_\parallel$$

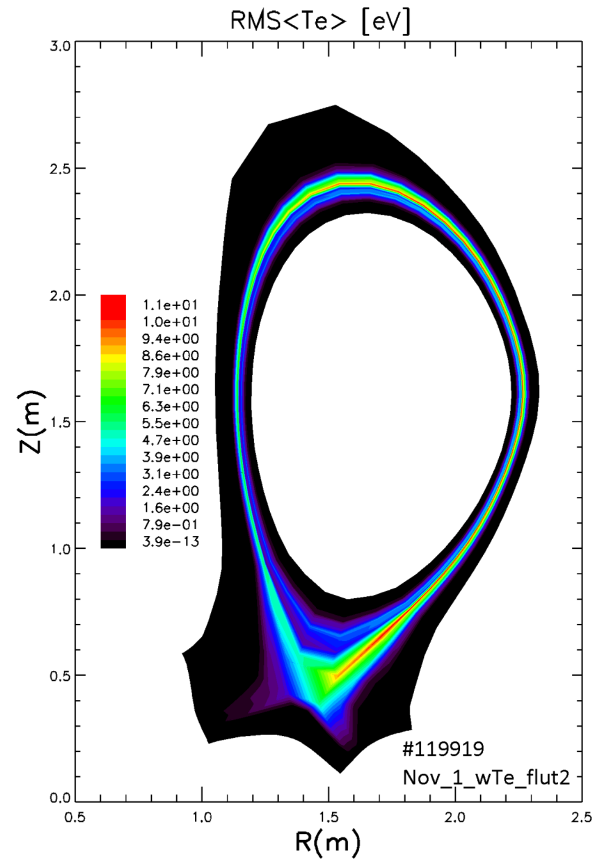
$$\frac{\partial V_{\parallel i}}{\partial t} + V_E \bullet \nabla V_{\parallel i} = -\frac{1}{N_i M_i} \nabla_\parallel P$$

$$\frac{\partial T_e}{\partial t} + V_E \bullet \nabla T_{e0} = \frac{2}{3N_0} \nabla \bullet \left(\kappa_\parallel^e \nabla_\parallel T_e\right), \quad \kappa_\parallel^e = 3.2 \frac{n T_{e0} \tau_e}{m_e}$$

$$\mathbf{E} = -\frac{1}{c}\frac{\partial}{\partial t}\mathbf{A}_\parallel - \nabla \varphi, \quad -\nabla_\perp^2 \mathbf{A}_\parallel = \frac{4\pi}{c} \mathbf{j}_\parallel, \quad \mathbf{B} = \nabla \times \mathbf{A}_\parallel + \mathbf{B}_0$$

$$\varpi = \nabla \cdot (e Z_i N_i \nabla \varphi) \approx e Z_i N_i \nabla^2 \varphi \qquad \nabla_\parallel = \mathbf{b}_0 \cdot \nabla + \tilde{\mathbf{b}} \cdot \nabla$$

- Electromagnetic with $\nabla_\parallel = \mathbf{b}_0 \cdot \nabla + \tilde{\mathbf{b}} \cdot \nabla$ in the vorticity eqn.
- Actual DIII-D geometry
- DIII-D - like fixed background profiles for shot 119919
- Includes T_e fluctuations and parallel heat conduction

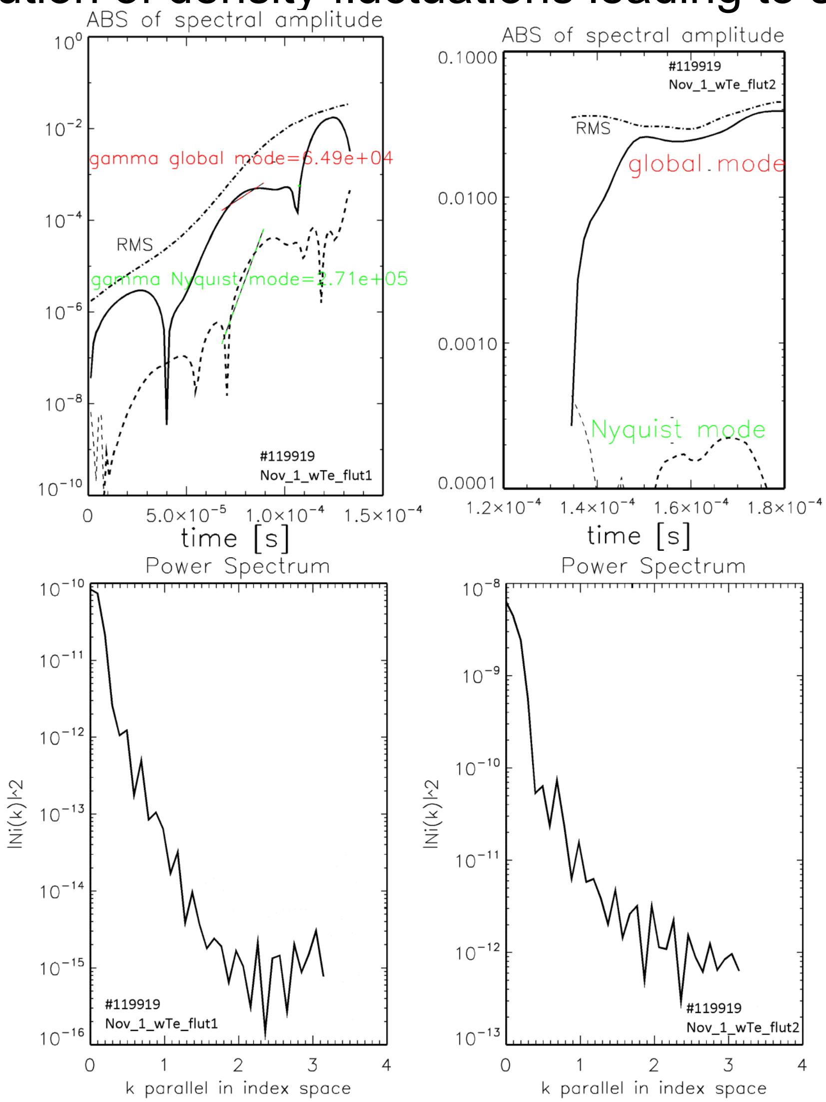


B. Cohen, et al., APS DPP 2011

BOUT-06 produces saturated turbulence for DIII-D geometry with δT_e, parallel thermal conduction, and magnetic flutter

- Evolution of density fluctuations leading to saturated amplitudes and spectra

BOUT



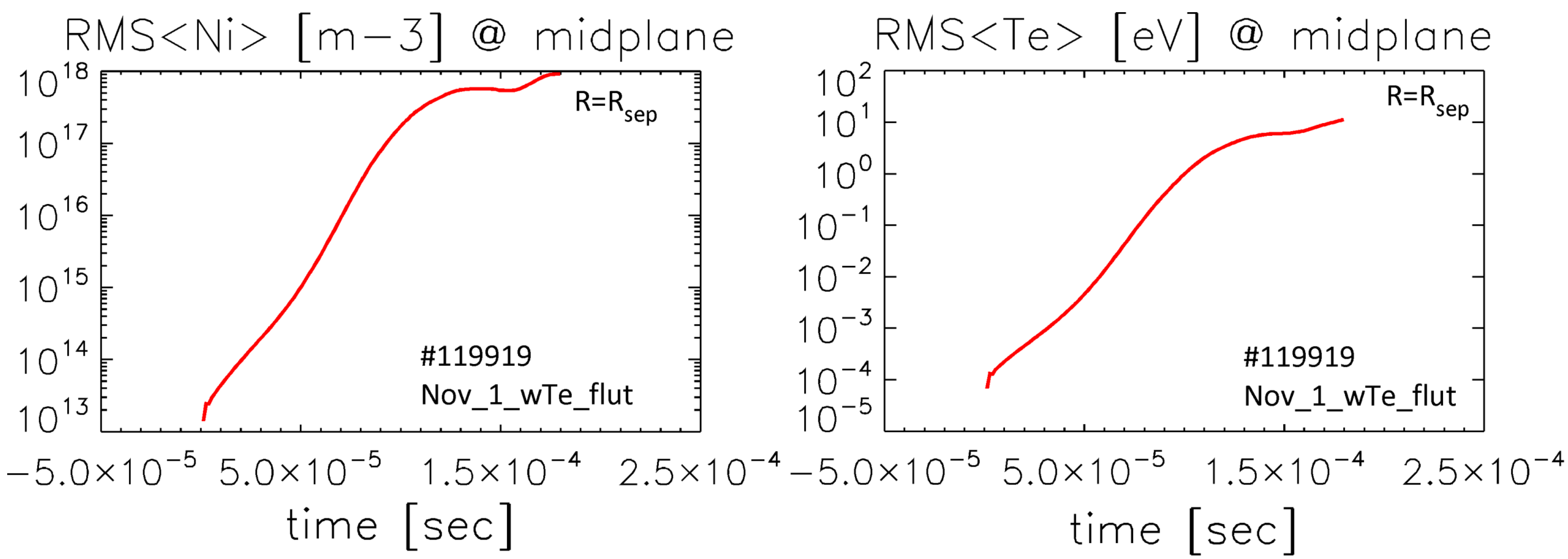
- Saturation at ~1.5×10^{-4}s

- With T_e fluctuations, electron parallel thermal conduction, and $\nabla_{\parallel} = \mathbf{b}_0 \cdot \nabla + \tilde{\mathbf{b}} \cdot \nabla$

B. Cohen, et al., APS DPP 2011

History of rms fluctuation amplitudes in midplane at separatrix with electron parallel thermal conduction and magnetic flutter

BOUT

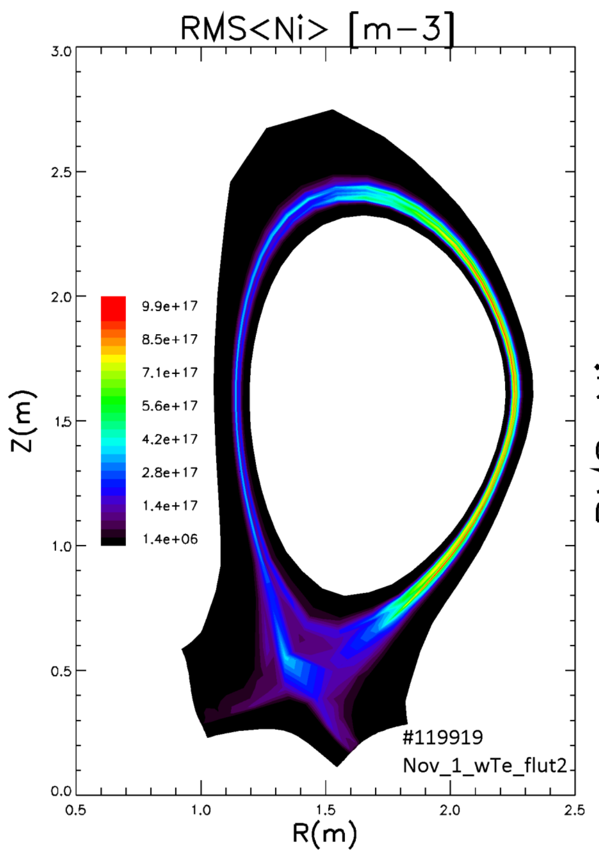


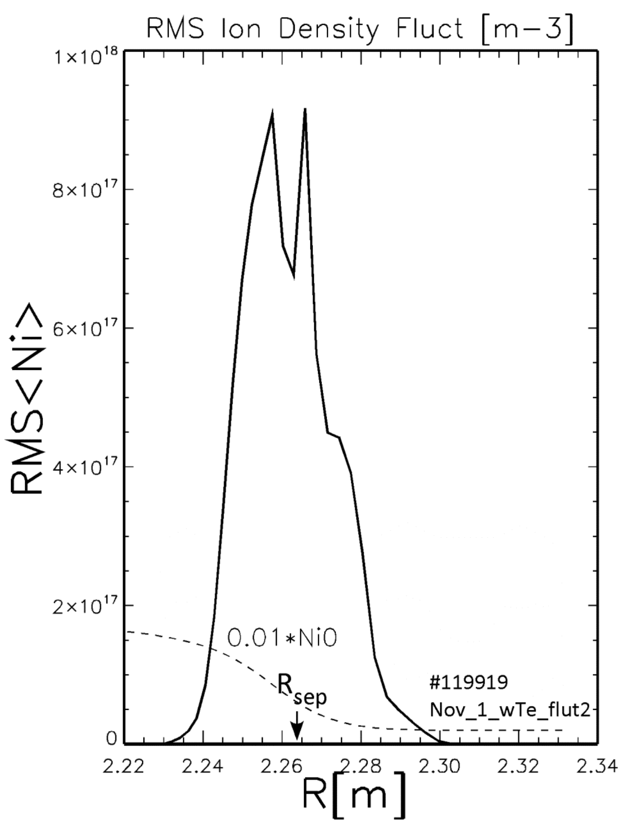
- With T_e fluctuations, electron parallel thermal conduction, and $\nabla_{\parallel} = \mathbf{b}_0 \cdot \nabla + \tilde{\mathbf{b}} \cdot \nabla$ in vorticity equation

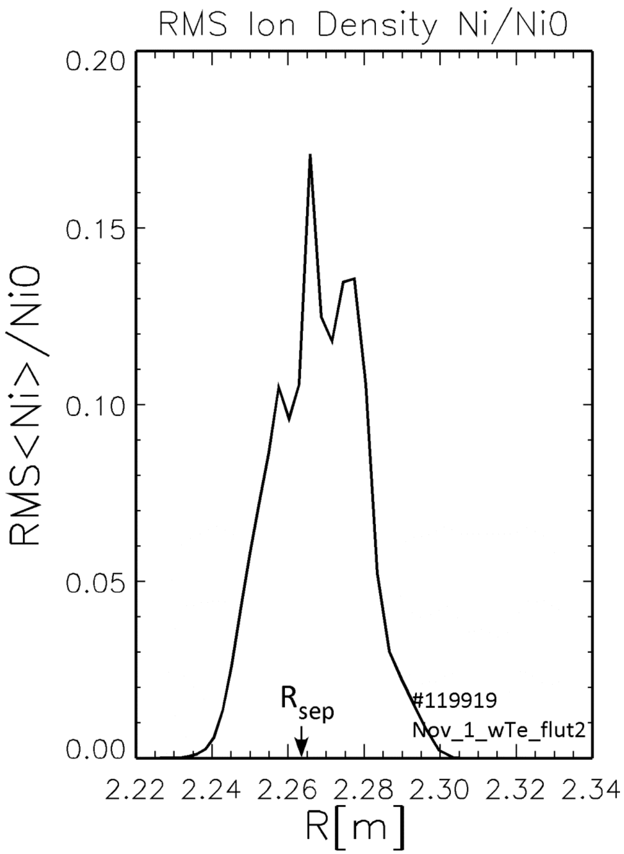
B. Cohen, et al., APS DPP 2011

Time-averaged ion density fluctuations in the midplane saturate at ~10-15% and peak near R_{sep}

BOUT





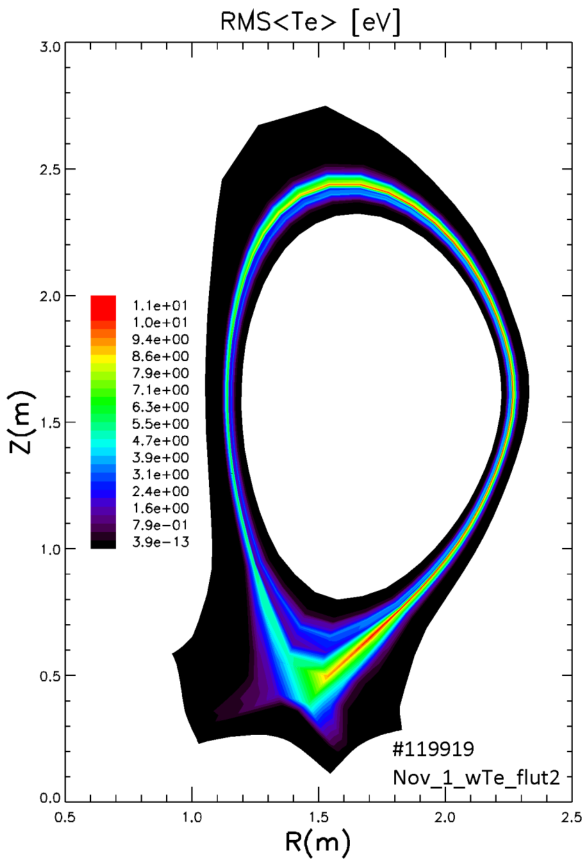


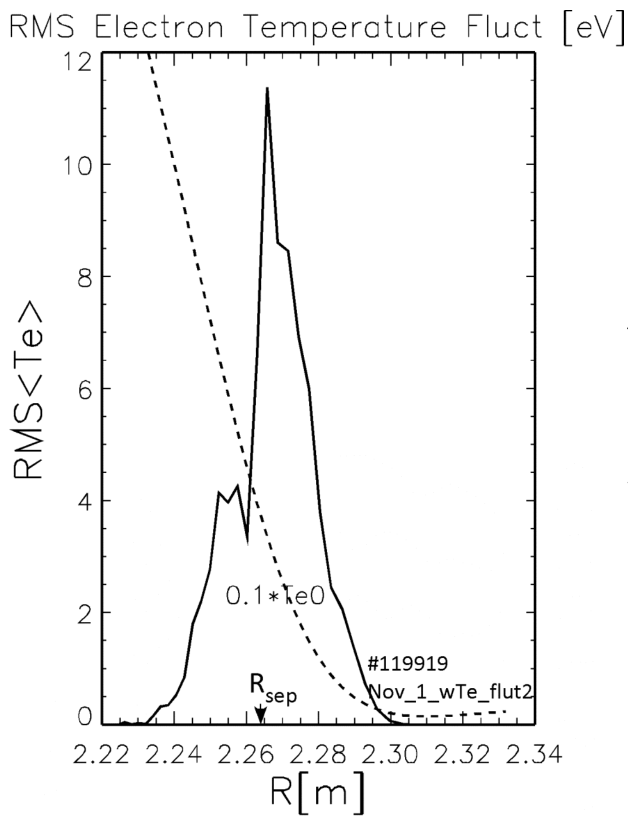
- With T_e fluctuations, electron parallel thermal conduction, and $\nabla_{\parallel} = \mathbf{b}_0 \cdot \nabla + \tilde{\mathbf{b}} \cdot \nabla$

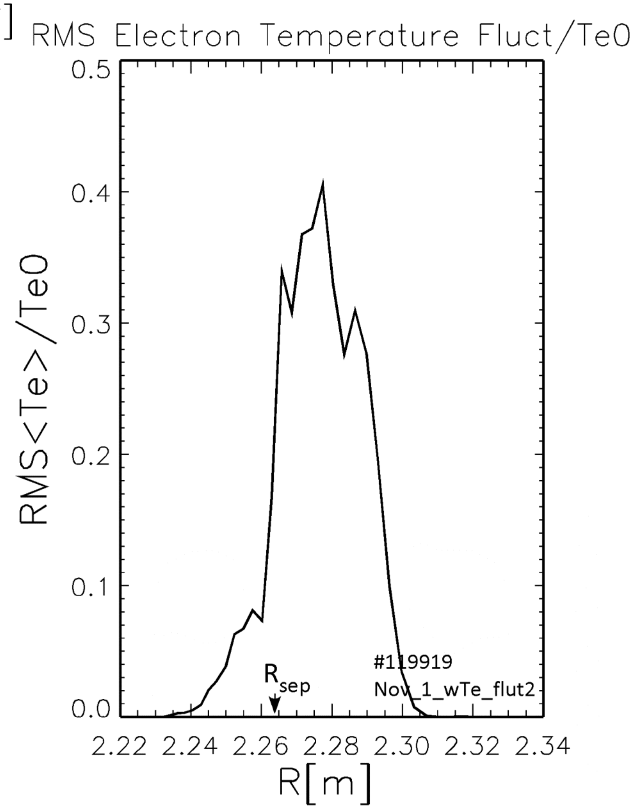
B. Cohen, et al., APS DPP 2011

Time-averaged T_e fluctuations in the midplane peak near the R_{sep} and saturate at ~25-40% relative amplitude

BOUT





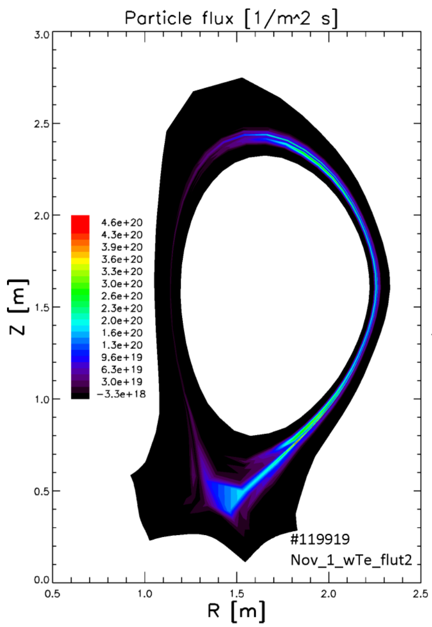


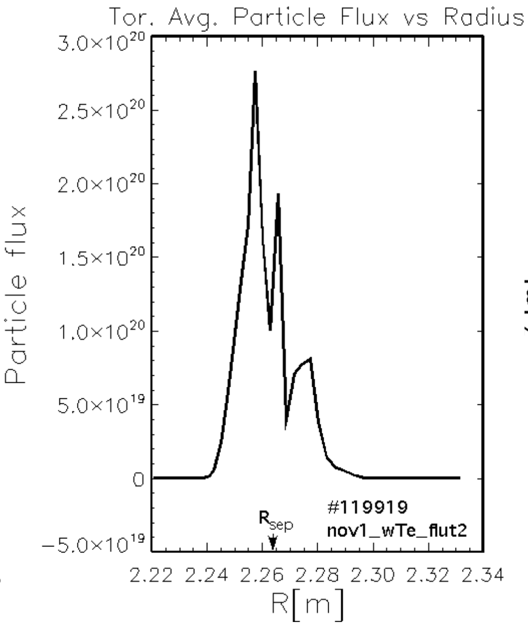
- With T_e fluctuations, electron parallel thermal conduction, and $\nabla_{\parallel} = \mathbf{b}_0 \cdot \nabla + \tilde{\mathbf{b}} \cdot \nabla$

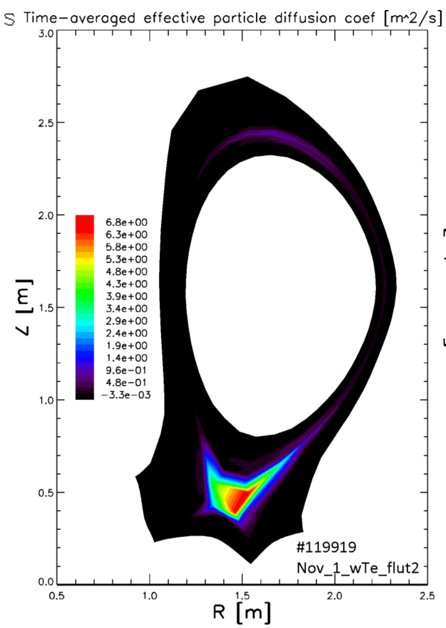
B. Cohen, et al., APS DPP 2011

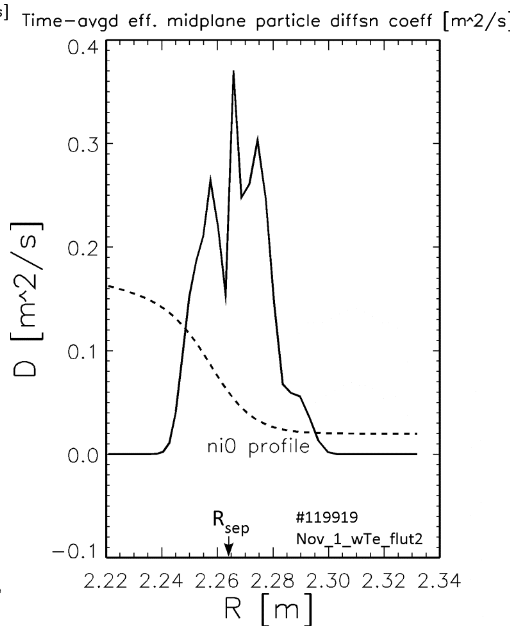
Time-averaged ion particle diffusion coefficient in the midplane saturates at < 0.3-0.4 m^2/s

BOUT







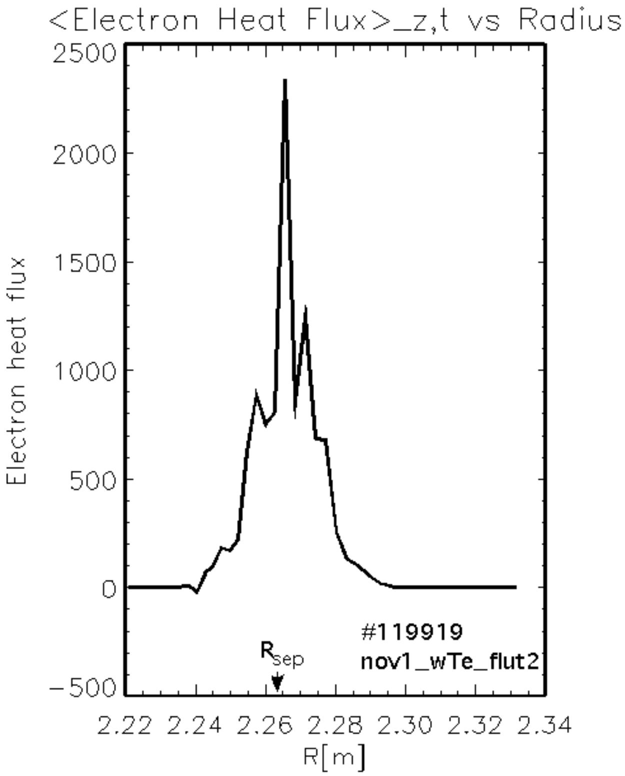


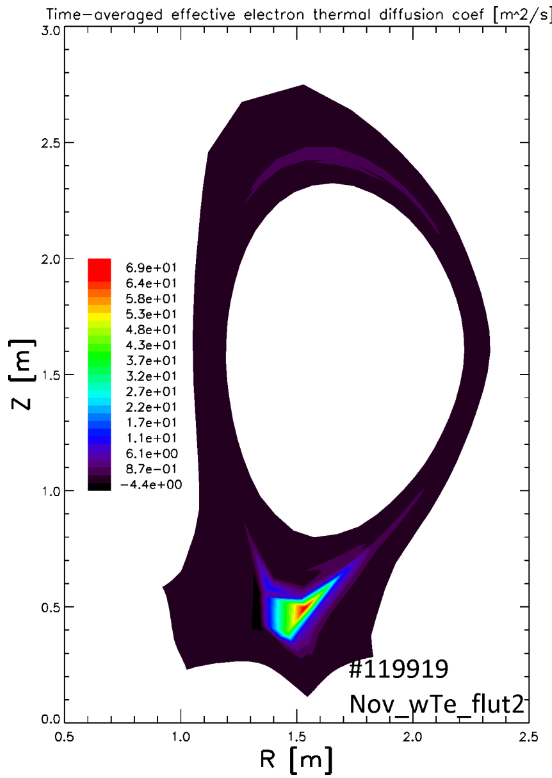
- With T_e fluctuations, electron parallel thermal conduction, and $\nabla_{\parallel} = \mathbf{b}_0 \cdot \nabla + \tilde{\mathbf{b}} \cdot \nabla$

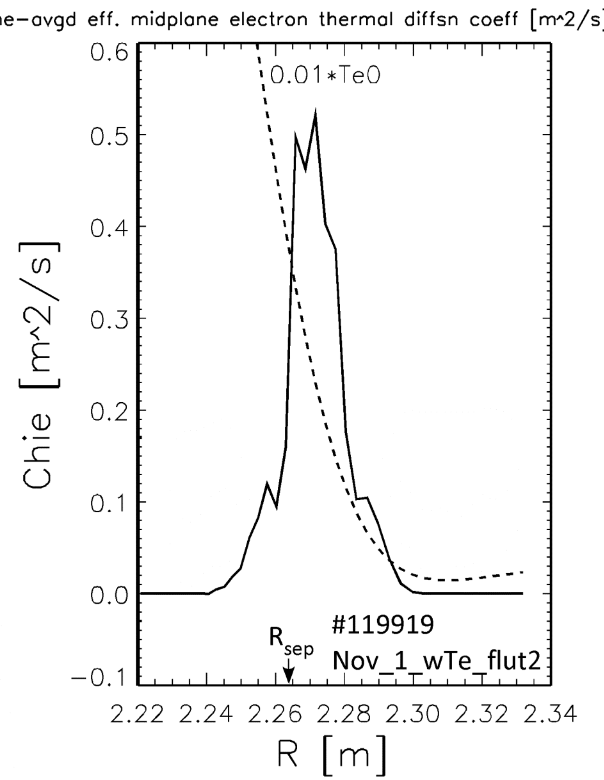
B. Cohen, et al., APS DPP 2011

Time-averaged electron thermal diffusion coefficient in the midplane saturates at ~0.5 m^2/s

BOUT







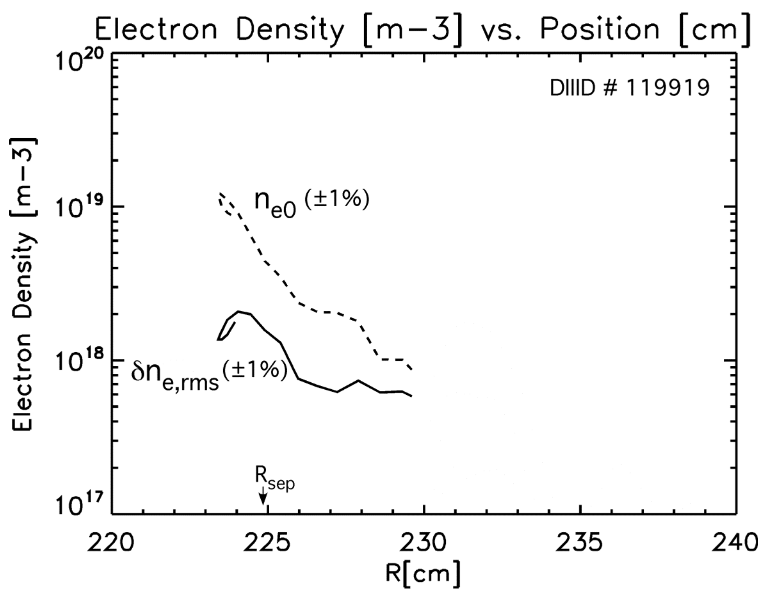
Note: Here heat flux (conductive) $= N_0 < \delta\tilde{v}_r \delta T_e >_{tor,t}$, and $\chi_e = -N_0 < \delta\tilde{v}_r \delta T_e >_{tor,t} / N_0 \nabla T_{e0}$

- With T_e fluctuations, electron parallel thermal conduction, and $\nabla_\parallel = \mathbf{b}_0 \cdot \nabla + \tilde{\mathbf{b}} \cdot \nabla$

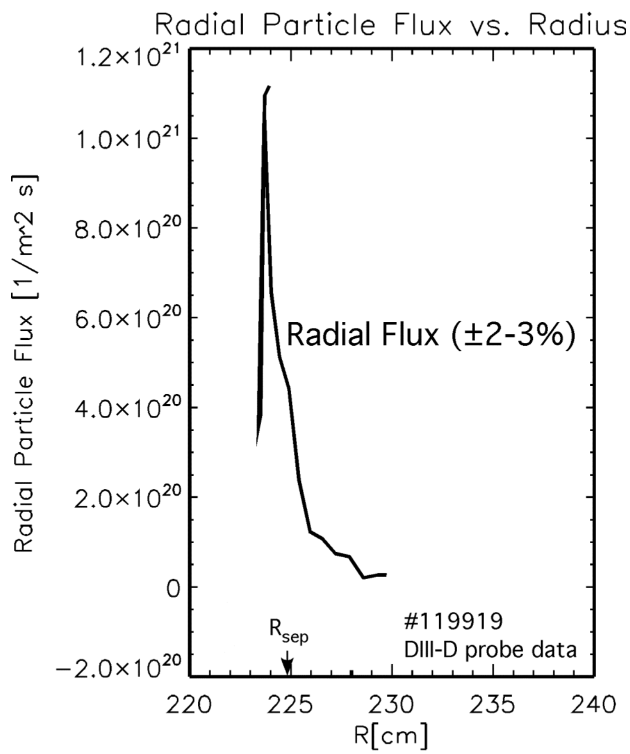
B. Cohen, et al., APS DPP 2011

Langmuir Probe Data for DIII-D #119919 (J. Boedo)

Electron density and radial particle flux vs. radius -- relative density fluctuations exceed ~20%



Probe signals decrease below noise levels for R > 229 cm.



Typical experimental rms density fluctuations at the separatrix are 24-50%
There is evidence that δn and the radial flux in the midplane peak near R_{sep} as in BOUT results.

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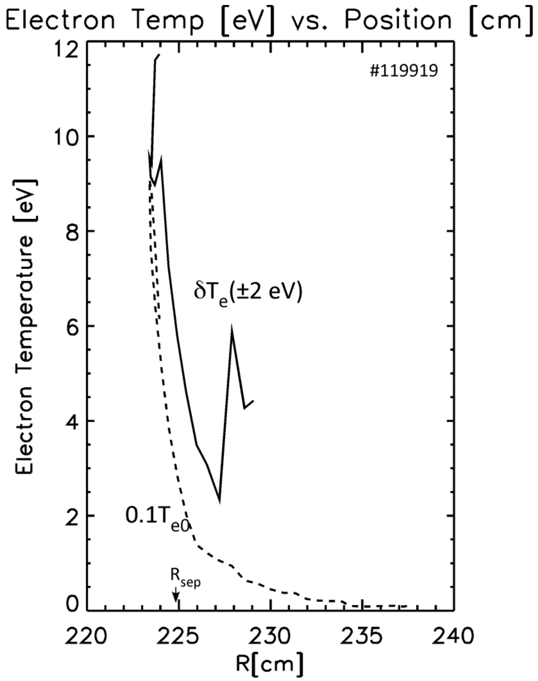
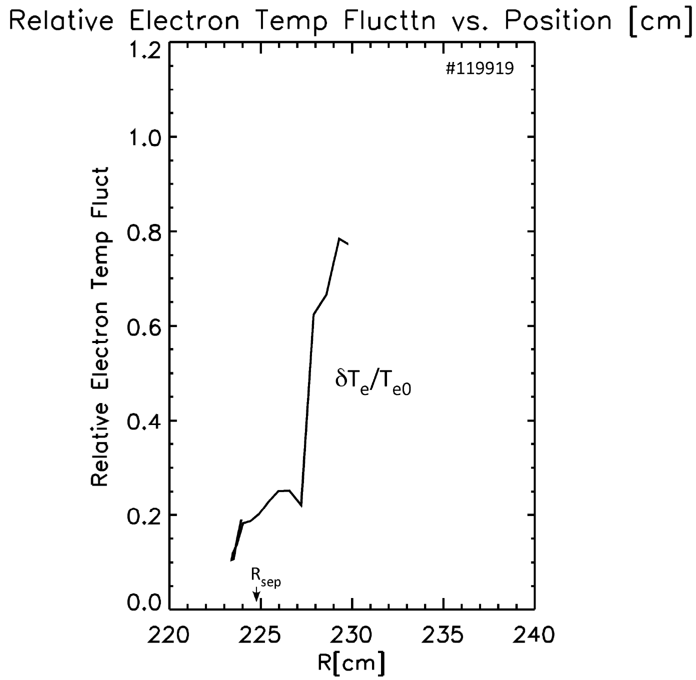
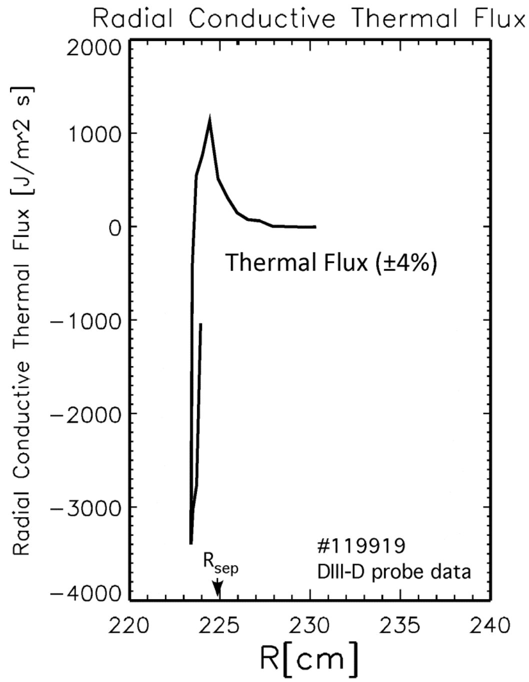
Langmuir Probe Data for DIII-D #119919 (J. Boedo)

Electron temperature fluctuations in midplane exceed 10%







Probe signals decrease below noise levels for R > 229 cm.

Typical experimental rms δT_e fluctuations at the separatrix are 10-25%
δT_e and the probe fluxes in the midplane usually peak near the separatrix as in BOUT results.

B. Cohen, et al., APS DPP 2011

Summary: As the physics model becomes more complete, the agreement of BOUT results with DIII-D probe data improves

- BOUT algorithmic issues -- control of an odd-even numerical contamination allows us to perform DIII-D simulations
- Comparison of suite of BOUT simulations to shot #119919: peak values in midplane at saturation near R_{sep}

Bout simulation	$\langle \delta N_i \rangle_{rms}$ ($10^{18}\ m^{-3}$)	$\langle \delta T_e \rangle_{rms}$ (eV)	Radial Particle Flux ($10^{20}\ /m^2\ s$)	D_r (m^2/s) local	Radial Heat Flux $= \frac{3}{2} N_0 < \delta\tilde{v}_r \delta\tilde{T}_e >$ ($10^3\ J/m^2\ s$)	χ_e(m^2/s), local (conductive)
#1: $\delta T_e=0$	0.95	N/A	1.8	0.4	N/A	N/A
#2: $\delta T_e \neq 0$ $\kappa_{\parallel e}=0$	1.0	43	4.3	0.77	54	7.2
#3: $\delta T_e \neq 0$ $\kappa_{\parallel e} \neq 0$	0.58	5.8	1.0	0.17	0.72	0.2
#4: $\delta T_e \neq 0$ $\kappa_{\parallel e} \neq 0$ & $\tilde{\mathbf{b}} \cdot \nabla$	0.9	11	2.8	0.38	3.6	0.8
DIII-D #119919 probe data	2.0	10	11.0	~0.15-0.2 ‡	1.2	~0.4 ‡

‡Typical, flux-surface-averaged values for L-mode discharges in DIII-D inferred from UEDGE

B. Cohen, et al., APS DPP 2011